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THE ARCTURUS: EQUIPMENT AND OPERATION.*[1]

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(Figs. 2–28 incl.)

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INTRODUCTION

In fitting out the *Arcturus* for oceanographic exploration, so many problems, both old and new, were approached that it seems a pity not to give others the benefit of our experience in solving them. With this in mind I have endeavoured to give an account of our ship that is not only descriptive but critical.

This paper does not pretend to be a review of oceanographic appliances as it mentions only those devices used during the 1925

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* The photographs illustrating this paper were made by Ernest B. Schoedsack; the diagrams (except Fig. 15) were drawn by the Author.

[1] Contribution, New York Zoological Society Department of Tropical Research, No. 247.

Fig. 2. The S. Y. *Arcturus*. The ship is higher out of the water than usual, as the coal bunkers were almost empty when this photograph was taken.

expedition of the *Arcturus*. It represents, more than anything else, the answers to many questions, that we, as inexperienced oceanographers, had to solve.

We were indebted for much information both before and during the expedition, to the published descriptions of other oceanographic vessels, especially to the account of the *Michael Sars* given in "The Depths of the Ocean," by Murray and Hjort; to the accounts of the *Princess Alice* and the *Hirondelle;* and notably to the various papers relating to the United States Fisheries Steamer *Albatross*.

I take this occasion to express my gratitude to Mr. William Beebe for the many opportunities that he has given to me both before and during this expedition. I would also like to thank Dr. Charles J. Fish of the Bureau of Fisheries, for much valuable information and criticism.

During the expedition the sounding machinery and nets were in the hands of Mr. William Merriam and Mr. Jay F. W. Pearson, and we are indebted for the successful operation of these and many other devices to these gentlemen. The supervising of the dredging and dredging machinery was in the capable care of Chief Officer Robert G. MacLoughlin and Captain James S. Howes and we are thankful to them for the efficient functioning of their departments.

The changes to the ship were designed and supervised by Mr. Edwin Bennett, and I am grateful to him and to Mr. Charles C. Yates for many suggestions.

Although the modern science of oceanography is a mere infant of fifty-odd years, it has grown to such an extent that specialization in the solving of the many problems associated with the study of the sea has been the inevitable result. Superficially, oceanography can be divided into the physical aspect and the biological. But these two divisions cannot be entirely disassociated from each other, as in many ways they are closely united and problems concerning one are often intimately linked with the other.

The voyage of the *Arcturus* was dedicated mainly to the biological side, although no opportunity was lost to obtain physical data or specimens, such as soundings, bottom samples, temperatures at various depths, samples of water at different depths for the determination of salinity and density, and observations on weather, winds, currents and barometric pressure.

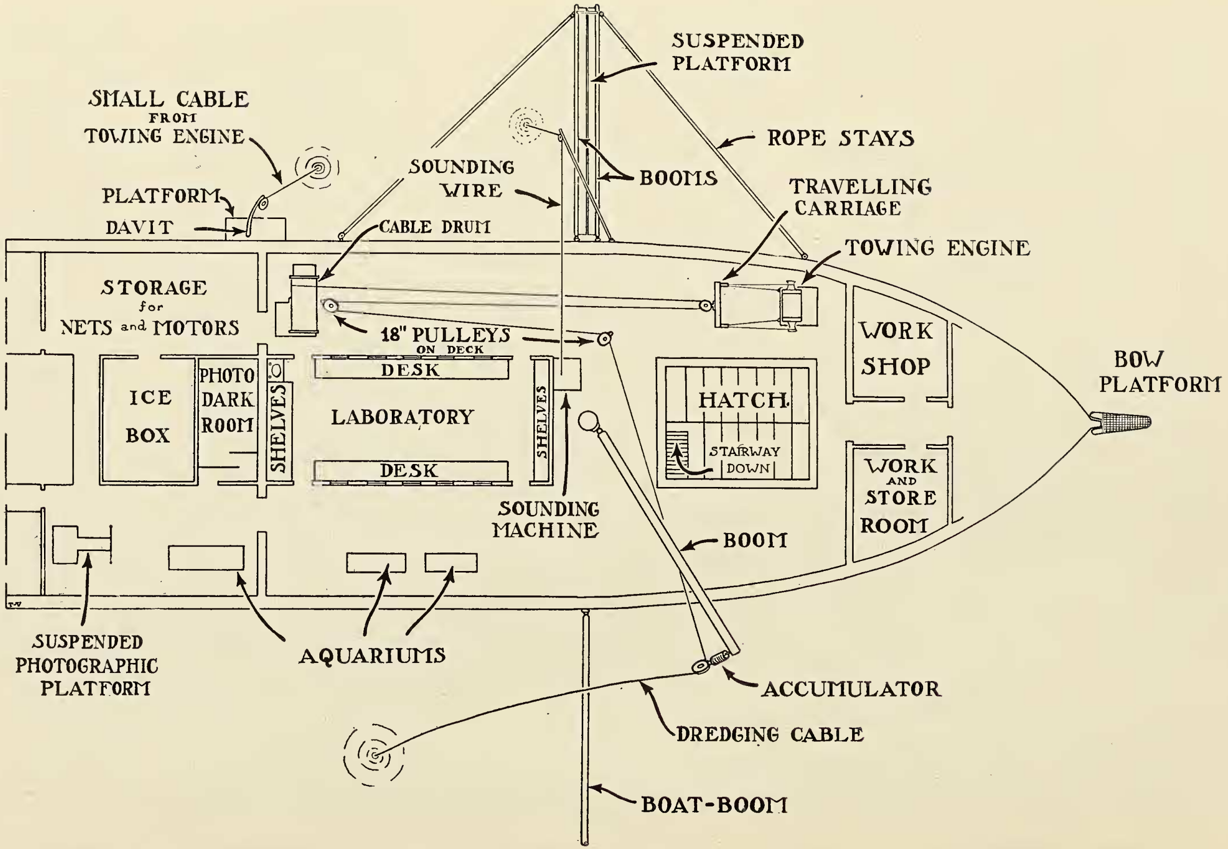


Fig. 3. Sketch showing the arrangement of the forward half of the main deck, also the method of leading the cable.

To change the *Arcturus* from a prosaic cargo-carrier to an expeditionary vessel capable of remaining at sea for long periods of time, required a great many alterations, not only in the special apparatus necessary for the exploration of the depths of the ocean, but in the construction of additional ice-boxes capable of holding six months' provisions, new cabins for officers, new dynamos to furnish the extra electrical current required, additional coal bunkers, and dozens of other things with which sea-faring men are acquainted.

To explain the changes found necessary and the actions of the various machines that were used during the expedition, the simplest method will be to describe briefly, first, the *Arcturus* and the apparatus that was installed on board, and secondly, in order to correlate the activities of machinery and personnel, a day's operations at one of the stations made during the expedition.

THE SHIP

The *Arcturus* was built during 1919 in Bellingham, Washington, by the Pacific American Fisheries Company. She is a wooden vessel, fashioned of Oregon Pine, and built very sturdily to withstand the heavy seas and ice along the Alaskan coast. Her dimensions are as follows:—Length over all, 282 feet; Length between perpendiculars, 268 feet and 4 inches; Breadth, over the planking, 46 feet; Depth, molded, 26 feet; Gross tonnage, approximately 2,475 tons; and net tonnage, approximately 1,466 tons. She was launched as the *Clio*, but the Mariner's Star seemed a more fitting name for a vessel devoted to oceanography than that of the Muse of History.

The vessel has twin screws driven by two upright, reciprocating engines developing 750 horse-power each, which drive the ship at an "economical" speed of 6 to 8 knots, and a maximum speed of 9 to 10. For a vessel devoted to oceanographic work the possession of double propellers is an invaluable asset. Not only can the speed of the ship be varied to a greater extent, but the possibility of cutting a cable or tearing a net is practically eliminated when only the propeller on the opposite side of the ship from where dredging is going on is revolving.

The *Arcturus* is a coal-burning, steam-ship of the type known as a three-island, one-deck vessel. That is to say, she has three houses rising above the main or weather deck, a forecastle, a main

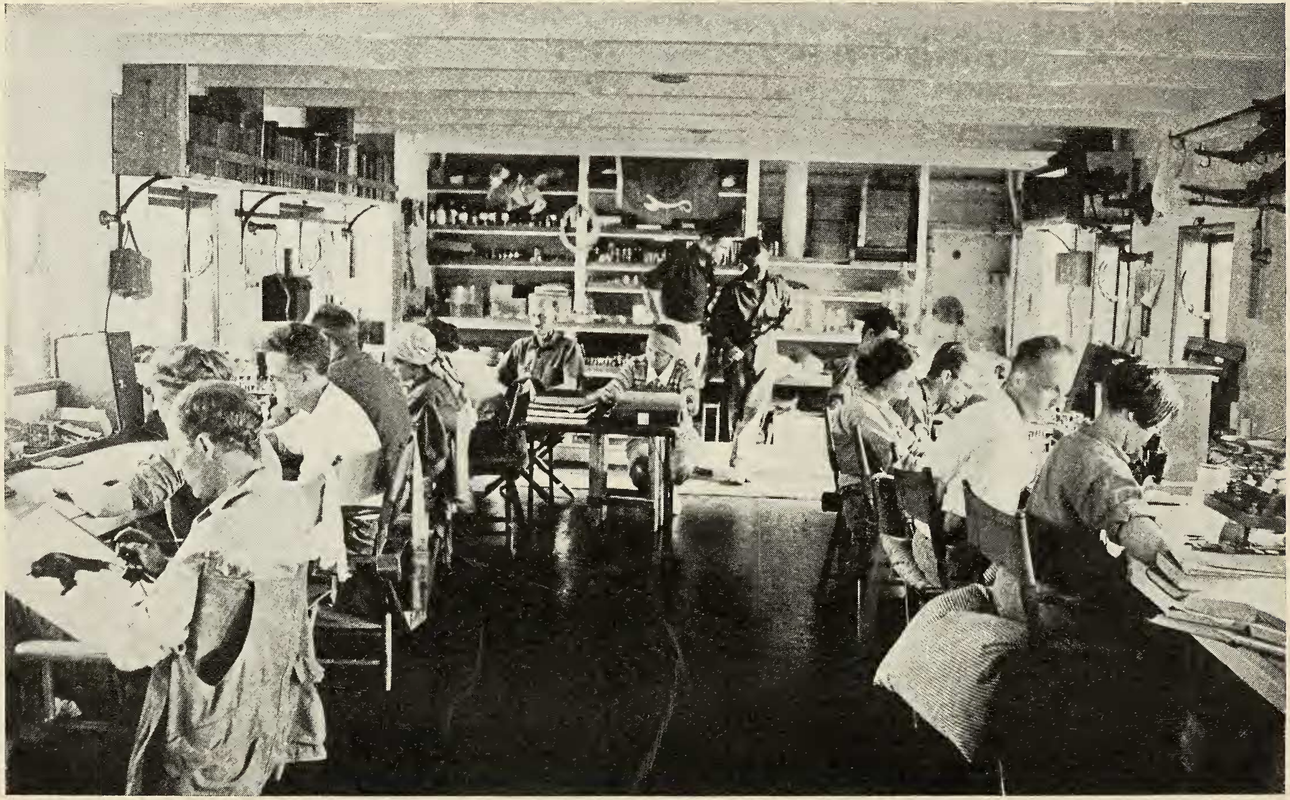


Fig. 4. The lower laboratory. View toward the after end.

house amidships, and a poop. The forecastle, originally the quarters of the firemen and sailors, was changed into two work-rooms, one for mechanical experiments and repairs, and the other for use as a store-room and for making plaster-of-paris molds of fish and other marine animals. The dispossessed mariners were transferred to the poop where adequate quarters were made available. This shifting of the crew to the after part of the ship was an arrangement that was ideal in every way, as it kept the entire forward half of the vessel free for oceanographic work and for the members of the expedition. The crew of the *Arcturus*, including the officers and two wireless operators, numbered thirty-five men.

The original midships island or house is the same outside as it was when the ship was launched, but many internal changes were made, especially on the main deck. This space,—the bridge casing, originally served as a coal-bunker. As the staff-members of the expedition occupied the officers' quarters on the bridge and boat decks, new cabins were constructed in the after half of this space, those on the starboard side being for engineers and those on the port side for deck officers. The forward half is now composed of extra ice-boxes, photographic dark-room, photographic gallery, space for aquariums, and storage space for nets and portable row-boat motors. (See diagram, Fig. 3).

The bridge-deck, immediately above the main or weather deck, contains the galley, crew's mess rooms, dining room for officers and members of the expedition, chief engineer's quarters and four cabins used by the staff. The next deck, the boat deck, contains seven cabins and the wireless room and hospital, the two latter being situated in a separate house aft. Above this deck is the navigating bridge and pilot house.

Immediately forward of this amidships house and above the original, second hatchway of the vessel, are the laboratories. The house in which they are contained is two decks high,—the floor of the lowermost one being a foot and a half above the level of the main deck. The second floor is at the level of the bridge deck. The lower laboratory, 36 feet long and 14 feet wide, was devoted to the examination and study of the various animals that were brought on board, and contained for this purpose suitable shelves and racks for chemicals and preservatives, vials, bottles and books. A 36-inch wide table placed at a suitable height for working extended along

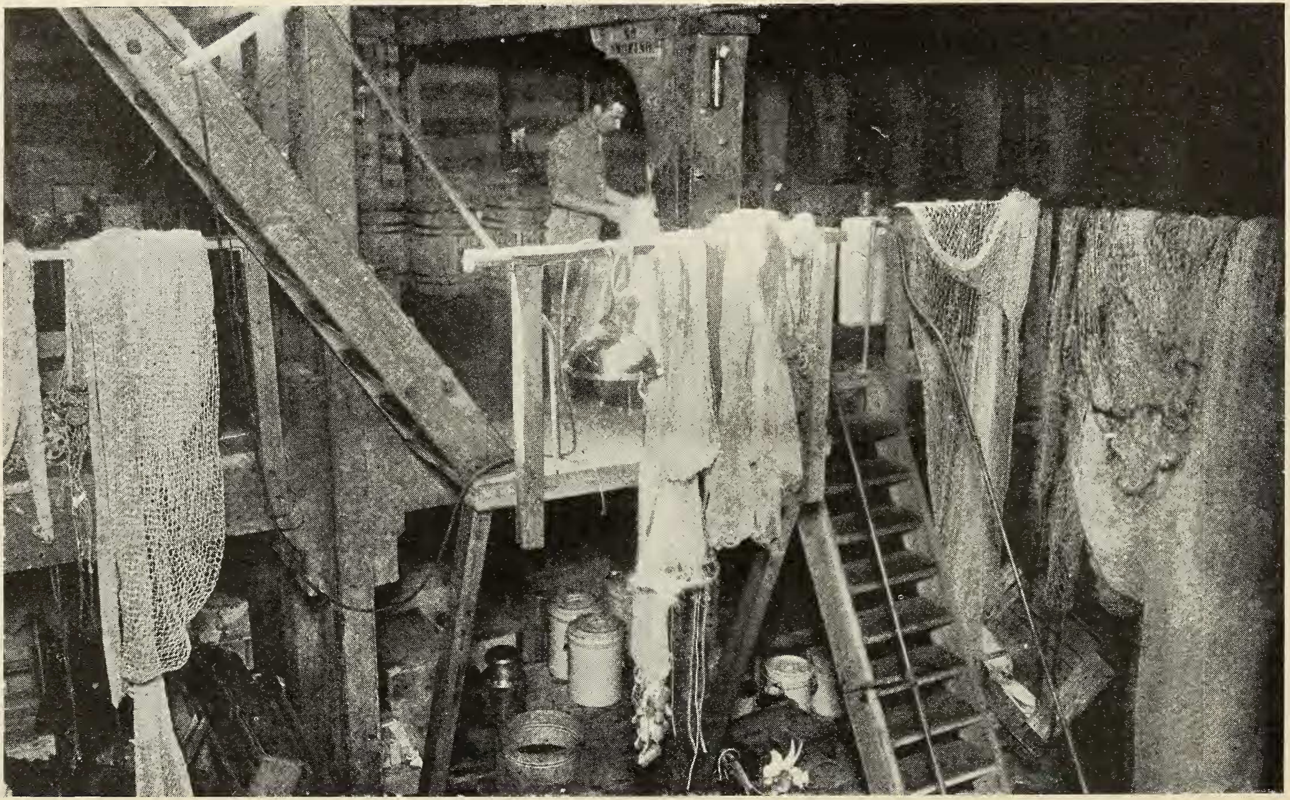


Fig. 5. The forward hold showing the two levels where nets, specimens and extra supplies were stored.

both sides of the room. A sink was also provided in this room. Ample light was obtained by a series of large, square windows opening on either side, and access was by two doors at either end. In stormy weather, large, wooden shutters completely enclosed the windows and protected them from the possibility of being broken by waves.

The upper laboratory is similar to the lower but slightly smaller and with only a single door at each end. It was devoted to the library, artists' quarters, chart-tables and chemical laboratory.

Of the four holds into which the hull is divided, the first was used as an expedition store-room, where nets were hung and surplus supplies were kept. The second and at times part of the third were used as coal bunkers. The third and fourth holds had extra water tanks, while the remaining space in the fourth hold was used for miscellaneous supplies such as lumber, coal for the galley, etc. Entrance to the first and third and fourth holds was through the hatchways and down especially constructed stairways. The second hold, over which the laboratory is now built, could not be entered except through the coaling ports or the engine and boiler rooms.

Additional changes to the vessel made necessary by its new vocation resulted in the installation of a 30-foot boat boom, 6 inches in diameter, on the starboard side of the ship, in line with the foremast. This was used for tying up our small boats and launches whenever the ship happened to be in harbour. It was so constructed that it could swing in along the side whenever the ship was at sea.

A metal crow's-nest, capable of holding two or three people, was installed at the top of the foremast.

BOOM-WALK

On the port side in line with the foremast, was constructed a device invented by Mr. Beebe, which we christened the boom-walk. Two 30-foot booms, 6 inches in diameter were installed, spaced 24 inches apart, and hinged in such a way that they could be swung outward over the water from the side of the ship. A narrow platform was suspended by ropes, between and about 3 feet below these. The outer ends of the booms were supported by a cable which ran through a pulley fastened to the mast just below the crow's nest, and thence to the deck where it was fastened. Rope stays prevented backward and forward motion.

Fig. 6. The boom-walk and a net towing in calm waters. The pulley attached to the boom over the boom-walk, is part of the sounding machinery.

This glorified pirate's plank served many purposes. Almost all of our surface tow-nets were towed from the boom-walk, and as it was thus possible to have them far out from the side of the vessel, the water through which they swept was undisturbed by the wash of the ship. We usually kept the boom-walk horizontal, although the outer end could be lowered to the water's edge, or, in heavy weather, raised above the possibility of hitting the water. We found that it was seldom necessary to swing it in, even when the ship rolled heavily.

Bow-platform

Of almost equal importance was a small, iron platform, also a device of Mr. Beebe's, dubbed the "Pulpit," which projected forward from the prow and could be raised or lowered to the very surface of the water. This platform was very simply made of angle-iron, and had a grating floor of welded wire. It projected 6 feet forward from the bow and was 2 feet 6 inches wide at the after end, while the inmate was protected from falling out by a railing placed 3 feet 3 inches from the floor. It was supported by blocks and tackle from a davit built over the bow, and was held in place by guys leading back to the after end of the forecastle. Access to the pulpit was by means of a Jacob's ladder from the deck of the forecastle.

Hours were spent on this platform by members of the expedition while the ship was in motion and whenever rough seas did not occur. Surface organisms and sea-weed could be captured with the greatest of ease by using a long-handled net in the untroubled waters just ahead of the ship.

Sounding Machinery

Before the *Arcturus* sailed, attempts were made to procure a sonic sounding machine; but in the few months before we left it was impossible to have one built. Instead we acquired an electrically operated Tanner-Bliss sounding machine of the latest type, similar to those used for deep-sea work by the Coast and Geodetic Survey. It was installed on an elevated platform on the port side of the main deck just forward of the laboratory.

The apparatus consisted of a 26.9-inch diameter drum, 3.875 inches wide and with flanges 1.375 inches high, made of duralumin,

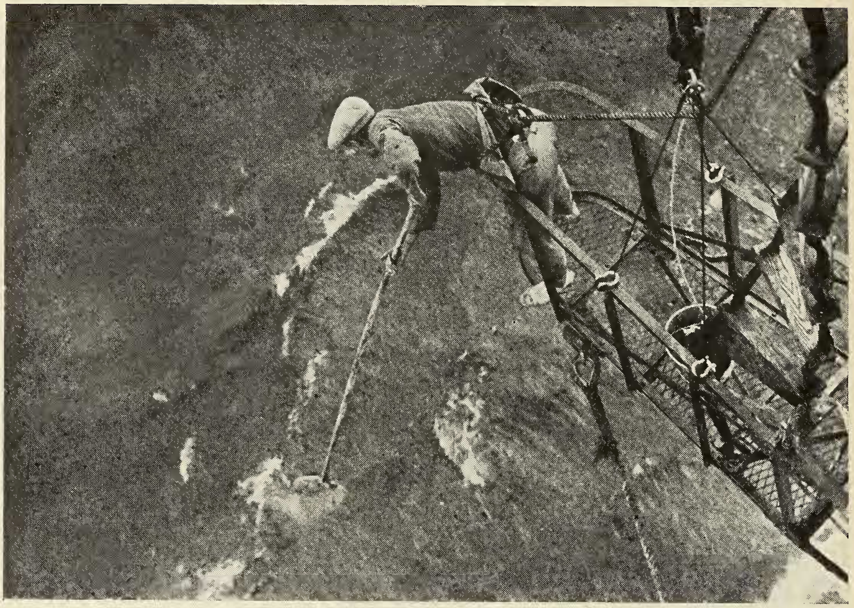


Fig. 7. Bow-platform. Usually the "pulpit," as the platform was called, was much closer to the water than this illustration shows. The rope about the waist was abandoned after the first week.

around which a maximum amount of 6 miles of steel piano wire, B. and S. gauge No. 21, was wound. This drum is connected with a 2 horsepower Diehl water-tight electric motor, the speed of which can be regulated by means of a rheostat. The clutch-brake is controlled by a single lever which moves the entire drum from side to side. When the lever is pushed away from the operator the inner portion of the rim of the drum is in contact with the brake and the wheel is held immovable; pushed half way over the drum is free and the wire can run out as fast as the weight can carry it; while if the lever is pulled toward the operator the inner rim of the opposite side of the drum comes in contact with a revolving wheel attached by a chain gear to the electric motor, and by this contact the wire can be reeled in.

This apparatus can be operated on small vessels by one man, but owing to conditions on the *Arcturus*, we usually had two or three,—one of whom read the meter wheel, recorded the time and saw that the wire was reeled on the drum correctly, while the second governed the ascent or descent of the sounding apparatus. The third man usually attached the sounding weight, watched to see that the wire was straight up and down as it descended, and removed the surplus water from the wire as it ascended.

When in use the sounding wire was led from the drum up to a meter wheel, thence to a "tell-tale" or indicator,—a long metal rod with a pulley at its outer end. This rod was pivoted to a bar just above the drum and was supported by the tension of the sounding wire caused by the weight suspended at the end. The slightest cessation of strain on the wire allowed the rod to fall downward; so that when the sounding weight and tube struck the bottom and the tension on the wire ceased, the time of impact was recorded immediately and the amount of wire let out could be read off on the meter wheel.

From the "tell-tale" the wire passed outboard to a small pulley at the end of a boom, just above and to one side of the boom-walk, and thence into the water. (See Figs. 6 and 12.)

To avoid the possibility of kinking the sounding wire when it happened to come in contact with the bottom, the last 50 or 100 feet was replaced by the "stray-line," which was merely a piece of softer, more malleable wire. Other ships have used hemp rope for the same purpose.

At the end of the wire was placed the sounding rod or tube. Many models have been designed and used by different vessels; the one used during this expedition being the Sigsbee sounding tube. This tube has two purposes,—the support and release of the sounding weight and the capture of a sample of the bottom. It is a hollow tube 16 inches in length with a shaft at its upper end containing a tumbler or catch. The tumbler is held in place, as can be seen in the diagram, by a trigger-like device or pawl. When the pawl is connected with the sounding wire and under strain, its lowermost end fits into a notch in the tumbler. Thus the tumbler is held firmly in place as it holds the wire that supports the weight. (See diagram, Fig. 10 for the action of this part of the sounding weight.)

When bottom is struck and the tension on the wire is released, the pawl drops downward, releases the tumbler, and allows the wire and weight to drop off.

At the lower end of the cylinder is a valve which is kept closed by a spring and which has a plunger projecting below the lower end

Fig. 8. The sounding machine. To the right is the "tell-tale rod." The controller handle and electric motor are between the two figures.

of the tube. Impact with the bottom causes the plunger to open the valve, whereupon a small amount of the bottom is sucked or forced into the tube, and on coming away from the bottom, the valve closes and the specimen is brought to the surface. Other details of this sounding machine, such as the arrangement for allowing the water to escape from the inside of the tube during the descent, as well as the reasons for thin piano wire, light-weight drum and heavy shot, can be found in Tanner's "Deep Sea Exploration," U. S. Bureau of Fisheries Bulletin, Vol. XVI, 1896.

The sounding shots or weights weighed 35 and 75 pounds,—the 75-pound weights being used for soundings below three or four hundred fathoms. They are pear-shaped, conforming as nearly as possible with stream line form, the lower end, as they descend, being the larger. The inner core is hollow, two inches in diameter, and fits around the sounding tube. At each side projects the outer portion of a nail,—20-penny nails being used in the 75-pound weights. These nails were cast with the shots and form a convenient projection by which the wire holding the sounding weight to the tube can be attached.

Practically the only mishap to machinery during the entire expedition was caused by the non-release of a sounding weight after it had hit the bottom. A sounding had been made in very soft bottom, and for some reason the weight persisted in remaining on the tube. Repeated attempts were made to release it, but without success. The wire was slowly reeled in, but the pressure exerted on the drum by the unusual additional weight was so great that the flange on one side of the drum broke off and pieces of metal were hurled about the deck.

Some of the soundings made during the expedition are among the records for speed as far as I know. At Station 105 in 2,803 fathoms, the entire sounding from the time the sounding tube left the surface until it came back with its sample, was taken in 51 minutes. This meant that the tube descended at the rate of 891 feet (148.5 fathoms) a minute, and ascended 542 feet (90.3 fathoms) a minute.

In shallow water of less than three or four hundred fathoms, we occasionally used mud snappers. These are heavily-weighted devices consisting mainly, of two scoop-like jaws. The smaller forms are made of a metal rod around which we placed a pear-shaped weight, and possess two small jaws on the lower end. The large mud snapper is shown in figure 9. It is a hollow tube, at the lower end of which are two jaws held together by a spring. Inside the tube is a rod, fastened at its lower end to the catches, projecting at the top and connected with the sounding wire. During descent the jaws are opened and held in place as shown. When the bottom is struck, the rod falls downward within the tube, thus releasing the catches, and the jaws are closed by the spring, retaining within their grasp whatever they have captured.

TRAWLING AND DREDGING MACHINERY

As the fisherman depends upon his line for pulling up his captured fish, so does an oceanographic expedition depend upon its

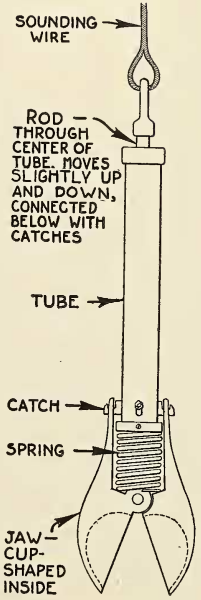
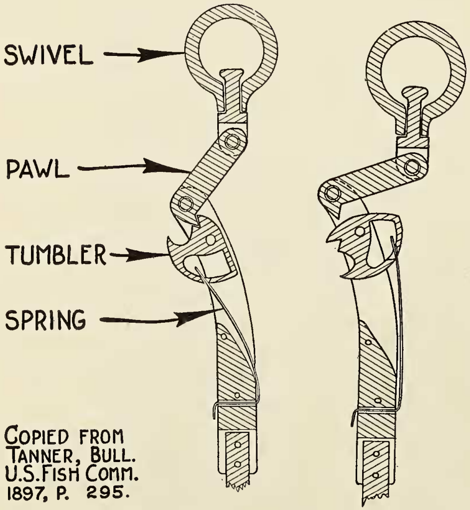


Fig. 9



COPIED FROM TANNER, BULL. U.S. FISH COMM. 1897, P. 295.

Fig. 10 *Left* *Right*

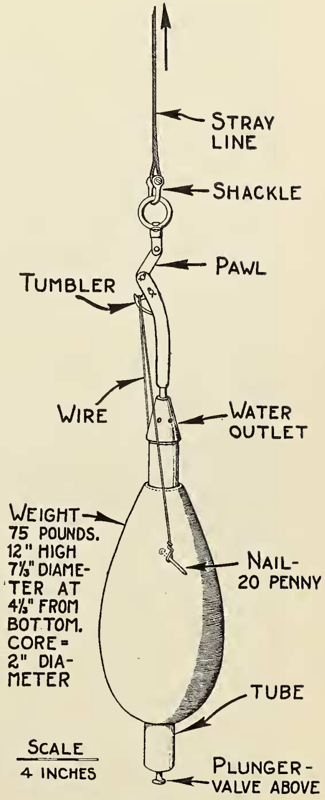


Fig. 11

Fig. 9. Large mud-snapper used on the expedition.

Fig. 10. Releasing mechanism at the top of the sounding tube. *Left*, held in place by the tension of the weight. *Right*, after the tube has struck the bottom and tension has been released.

Fig. 11. Sounding weight in place on the sounding tube and ready for use.

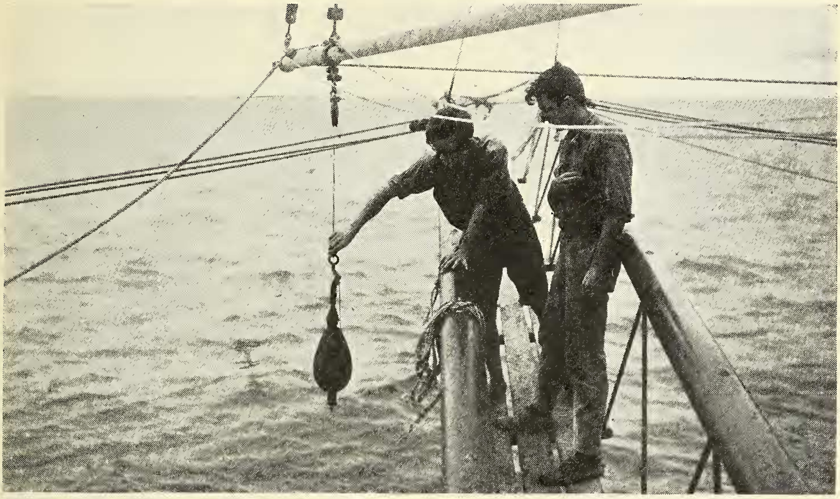


Fig. 12. The sounding weight and tube ready to go down.

line for pulling up whatever may happen to be caught. The line thus becomes an important, if not the most important piece of apparatus on board the ship. For admittedly one cannot bring back specimens from the deep if there is no means of getting nets and trawls down and of bringing them back.

For the work that we wanted them to do, the line, or, as it happens to be, the steel cable, had to be five nautical miles in length,—long enough to stretch up Broadway in New York City from the Battery to 79th Street, or up Fifth Avenue from Washington Square to 125th Street. Needless to say, this amount of heavy cable, ½-inch in diameter, required special drums and machinery to handle it, and a few interesting engineering problems were encountered before the plans were completed and the engines made.

The problem of producing the machinery capable of carrying the cable and of taking care of the sudden strains that might occur when the vessel was trawling or dredging was placed in the hands of Mr. Spencer Miller of the Lidgerwood Manufacturing Company. After six months of constant operation we can say that the machines produced from Mr. Miller's designs were perfect[1]. No trouble of

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[1] These machines have been described from a technical standpoint by Mr. Miller in the Pacific Marine Review for September 1925, and also in the Bulletin of the New York Zoological Society, Vol. XXVIII, No. 4, July 1925.

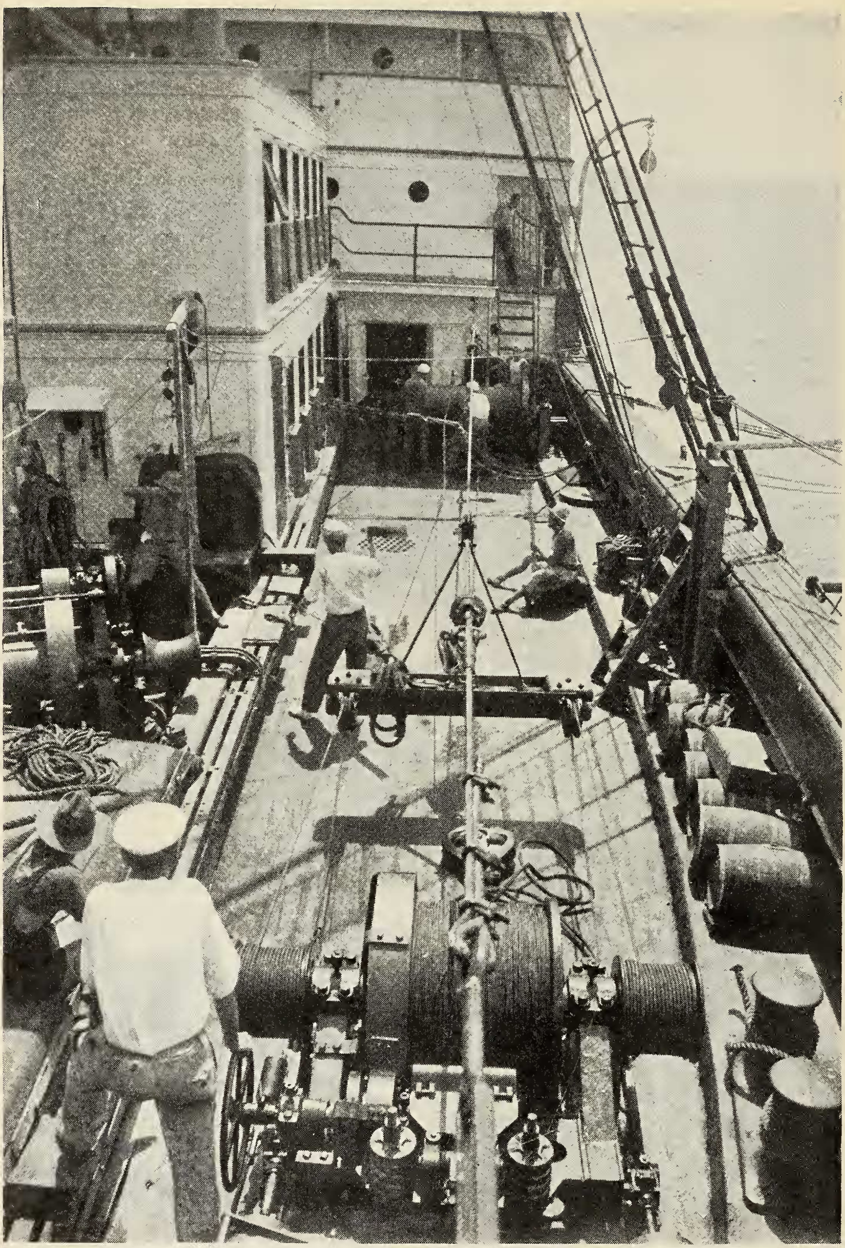

Fig. 13. Trawling and dredging machinery shown as the wire cable was being reeled in. Towing engine in the foreground. Surplus water is being beaten from the wire while in the background the cable is reeled onto the drum.

any kind was experienced during the voyage, and in emergencies the machines always worked as they should.

The trawling and dredging devices consisted of two machines. The larger engine, which held the main cable, had a drum with a solid steel core 10 inches in diameter, and with a steel flange at each end 48 inches in diameter and spaced 66 inches apart. Solid steel, carefully braced, was necessary to withstand the tremendous strains exerted both inwardly and to each side as the cable was wound under pressure onto the drum.

The drum was coupled by gears to a donkey engine which was controlled by a single lever, the upward movement of which let the cable out and the downward pulled it in. In the midway position the engine was stopped. The combined drum and engine were placed on the main deck just forward of the bridge on the port side.

The second machine was incorporated into the design to take care of possible jars and consequent breakage of the cable. It consisted of a small towing engine, similar to those used on sea-going tug-boats. These engines are made to maintain a constant tension and a constant length on towing cables when used between ships at sea. Thus when a vessel is being towed and a wave produces a violent tug on the tow line, the additional strain automatically activates the towing engine and a certain amount of line is paid out. As the strain relaxes the engine pulls in the line to its original length; thus the cable is kept from breaking and the tow from being uneven. How this principle was utilized on board the *Arcturus* will be shown later. This engine was placed on the main deck on the port side just aft of the forecastle, and in line with the main cable reel.

Suspended to a heavy cable between and above the two engines was a travelling carriage which could move up and down the deck from one engine to another. This carriage was connected by two cables, one on each side, to the towing engine. The lower half of each of these cables was firmly attached to the base of the engine, while the upper half was led to and wound around the small end drum of the engine.

When dredging on the bottom the cable was led, as shown in the diagram (Fig. 3) from the main drum to a sheave or large pulley on the travelling carriage and then to a pulley fastened to the deck just below the main drum. From here it went to another pulley fastened to the deck at the level of the main mast, and thence to a

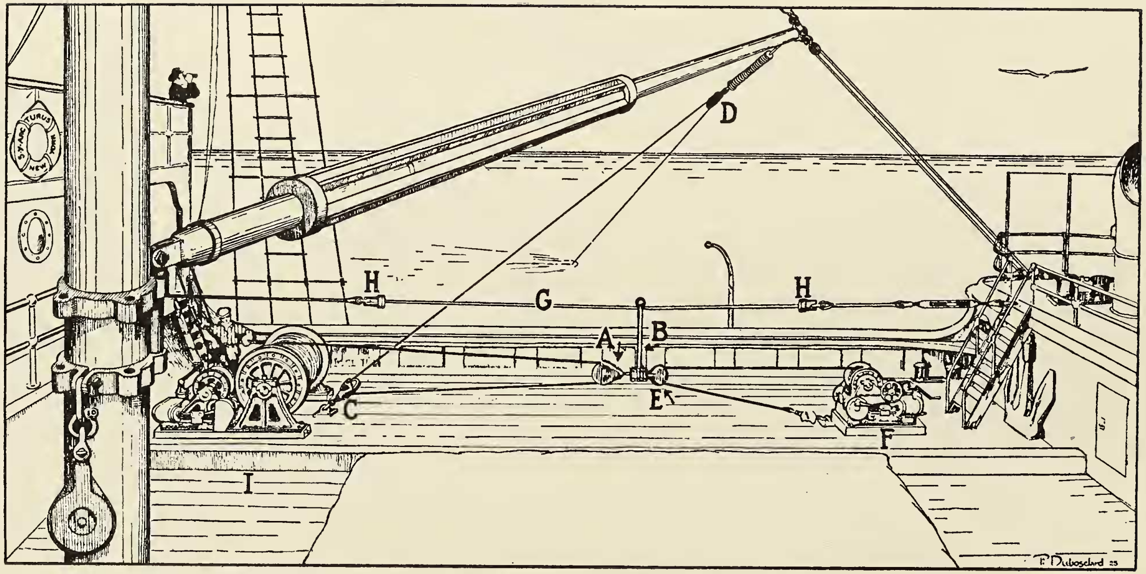

Fig. 14. Diagram showing the machinery used for operating the trawling apparatus. A, Pulley; B, Travelling Carriage; C, Pulley; D, Pulley at end of mast, connected with spring or accumulator; E, Pulley; F, Towing Engine; G, Cable from which travelling carriage is suspended; H, Stops, to prevent trolley from colliding with engines; I, Main Cable drum.

The actual rigging of the cable was slightly different, as it was impossible to show the two sides of the ship in this drawing. From a pen drawing by P. Duboslcard.

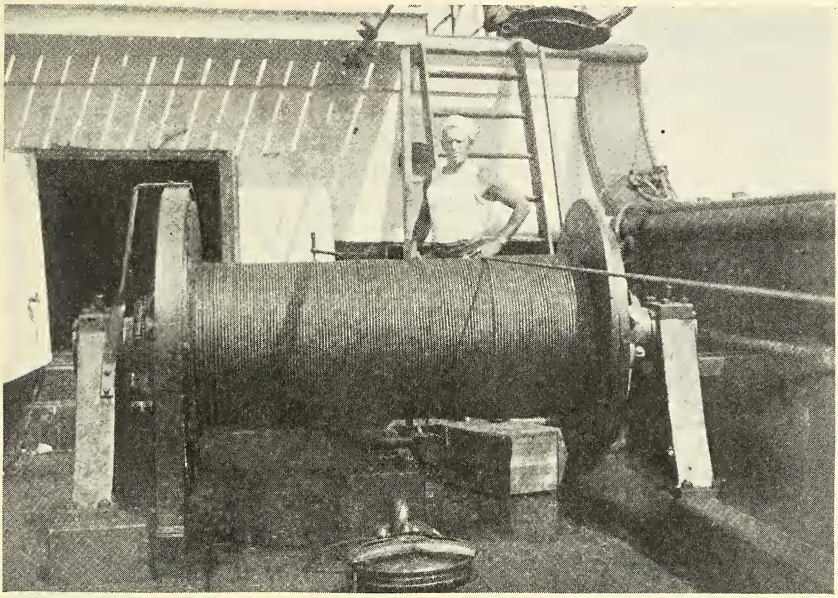

Fig. 15. The main drum holding the half-inch wire cable. About one-half the cable is being used for trawling.

pulley at the end of the starboard forward boom, from whence it passed into the sea.

The pulleys or sheaves were made of heavy steel and were eighteen inches in diameter. They were self-lubricating, as the inside of the wheel could be filled with oil which was gradually supplied to the axle. Larger diameter pulleys would have been better as the strain on the cable in passing around a sharp corner would have been considerably lessened by a larger sized wheel.

The pulley at the end of the boom was suspended from one or at times two large steel springs or accumulators. These accumulators were supposed to have a capacity of 10,000 pounds before the springs flattened. Their main reason for existence was to take care of sudden sharp strains on the cable, and in this way they co-operated with the tension apparatus in the towing engine.

The large cable on the *Arcturus* was ½ inch in diameter and formed of 6 wires of 19 strands each wound around a steel core. The solid core was deemed necessary because the wire was reeled in under full strain onto the drum. Other expeditions have taken much of the strain off the drum by using a separate engine to haul up the cable, and afterwards winding it up on an independent reel.

During operations, one man was stationed at the main drum and another at the towing engine. The second man, however, was by no means necessary, as the machine when adjusted, operated automatically. If the dredge, as it was pulled along the bottom, happened to hit an obstruction of sufficient size to stop it, the immediate increase in tension was felt all along the cable. When the tension reached 10,000 pounds,—the reading being shown on a dynamometer, the strain on the cable transmitted to the towing engine through the travelling carriage caused the valves of the towing engine to open. This enabled the cables connected to the travelling carriage to pay out. The carriage was thus able to move down the deck, shortening the distance between its original position and the main drum, and incidentally allowing the wire which had stretched up and down the deck to pass overboard. The carriage moved at such a rate that the wire was able to go out at the same speed or a little faster than the ship went forward, thus reducing the strain on the cable or at least not allowing it to increase. The time the carriage occupied in travelling the 50 feet down the deck, thus allowing 100 feet of cable to run out, occupied from 10 to 20 seconds,—an interval of time sufficient to allow the man stationed at the main drum to open the valves and let out cable. As soon as the automatic towing machine gave way the officer on the bridge signalled to the engine room to stop the engines. In the meantime as the ship lost headway the cable continued to be paid out and the travelling carriage, as the tension was relieved, automatically moved back to its original position. When the tension relaxed, the paying out of the cable was slowed down and the winchman merely kept the line taut. If the dredge was still caught the vessel could be brought back over it and maneouvered until it was released.

Whenever necessary the towing engine could be disassociated from the travelling carriage and used as a simple reeling engine. For this purpose the central drum was provided with 15,000 feet of one-quarter inch diameter blue center steel cable. This cable was used day after day for taking temperatures and obtaining water samples, and for the vertical and vertical closing nets.

In order to preserve and prevent the cables from rusting after contact with sea-water, they were oiled after every immersion. In

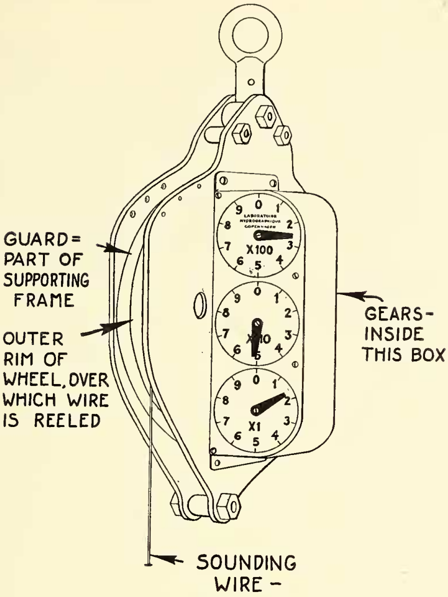

Fig. 16. Meter wheel.

addition to the oiling the members of the expedition took turns, two at a time, in pounding the cable with heavy wooden clubs before it was wound up on the drum. This procedure served a double purpose,—it gave us much needed exercise, and, more important, it removed the water from the interstices of the line. That this procedure was not as foolish as it sounds is attested by the excellent condition of the wire at the end of the expedition. Removal of the outer layer of solidified oil revealed shining steel wire as bright as the day it was made. Two hundred gallons of raw linseed oil were used on the cable during the expedition.

Meter Wheels, or Cable-Measuring Machines

In all cases the length of the wire, whether sounding wire or dredging cable, was measured by passing it over a meter wheel.

The meter wheels used on the *Arcturus*, which were procured from the Laboratoire Hydrographique in Copenhagen, are made of a single wheel around which the wire travels, connected by gears to a series of dials which give the length in units, tens and hundreds of meters.

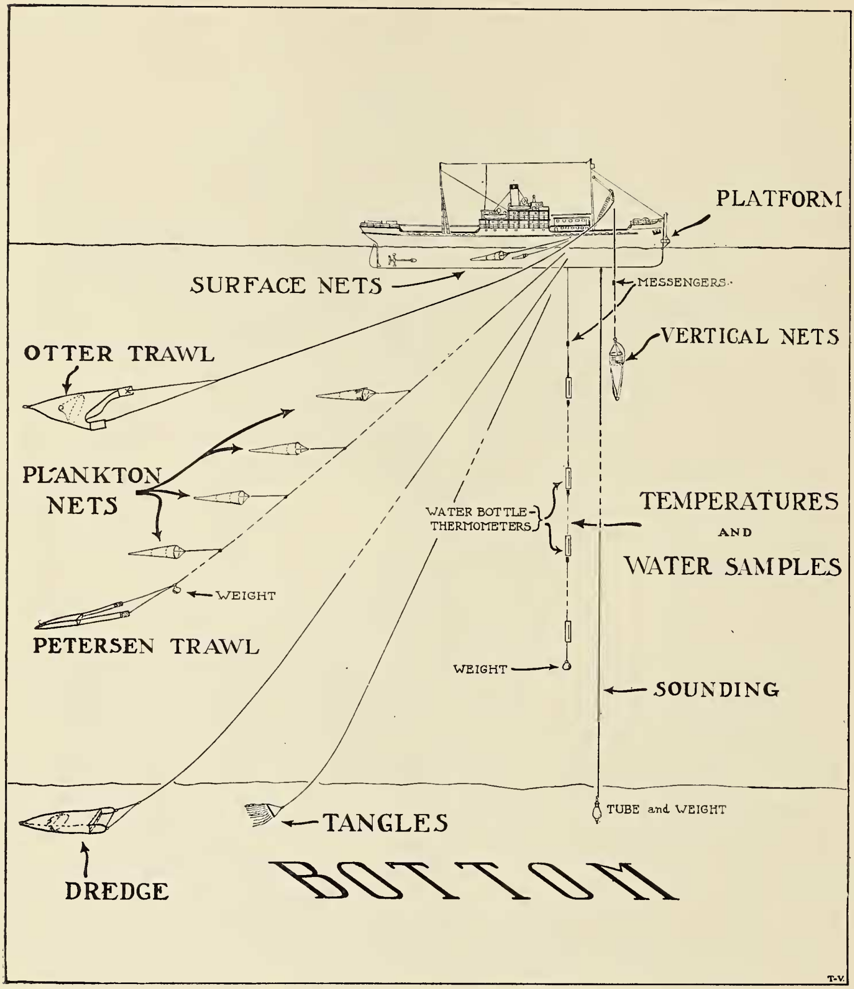

Fig. 17. Diagram of some of the devices used during the expedition.

Different sized wheels were used according to the size of the line. Caution was exercised to see that the cable made firm contact with the wheel in order that the registration would be correct. At the same time the wire could not be pressed down too hard, as grooves are easily worn into the metal and consequently errors in the length of cable might arise.

TRAWLS

The Blake beam trawl was used for most of our bottom work. This is a sled-like frame of iron or steel behind which trails a bag or net. As can be seen in the illustration, the sled runners are the same on both sides. Consequently it does not matter how the dredge reaches the bottom; it will always land right side up. Some of the earlier deep sea dredges were so made as to land on one side only; if they landed on the other they captured nothing.

The runners of the Blake trawl are 4 feet 6 inches long and 2 feet high, and they are held apart by ten-foot bars. Six foot wide trawls of the same kind were used during the expedition.

The following measurements of the nets used to trail behind are taken from the specifications furnished to the makers: Beam trawl webs, with mouth 2 feet high and 10 feet wide, trailing for 20 feet. First 12 feet to be of 3 inch mesh, medium 30 thread. Bag at end to be 1 inch mesh 16 thread, and with a drawstring at the end. Mouth to be roped to 9 thread tarred manila rope. Bag to be equipped with a funnel.

Nets made of heavier thread would have been better, but the specified nets worked very well during our trip. Nets for the 6 foot dredges are of similar construction, but proportionately smaller. On Saba Bank, a coral reef in the West Indies, we used a trawl-net made of ½-inch diameter rope. This worked successfully for a short time, but contact with the sharp edges of the bottom soon caused the ropes to fray.

For capturing the fish living on and near the bottom we successfully used otter trawls,—most of ours being somewhat smaller than those employed in shallow water by commercial trawlers. In addition to using them on the bottom we often towed them in mid-depths.

Otter trawls differ from beam trawls and dredges in that they have no iron sled in front to keep the mouth of the net open. The sled is replaced by two wooden boards placed some distance in front of the net and connected to it by ropes, or else fastened directly to the net. The two boards are attached to the towing cable by a rope bridle, the length of which in the larger nets used by us, was about 150 feet. Rigged in such a way (diagram page 73) the boards tend to pull apart as they are towed, and thus keep the mouth of the net open as widely as possible.

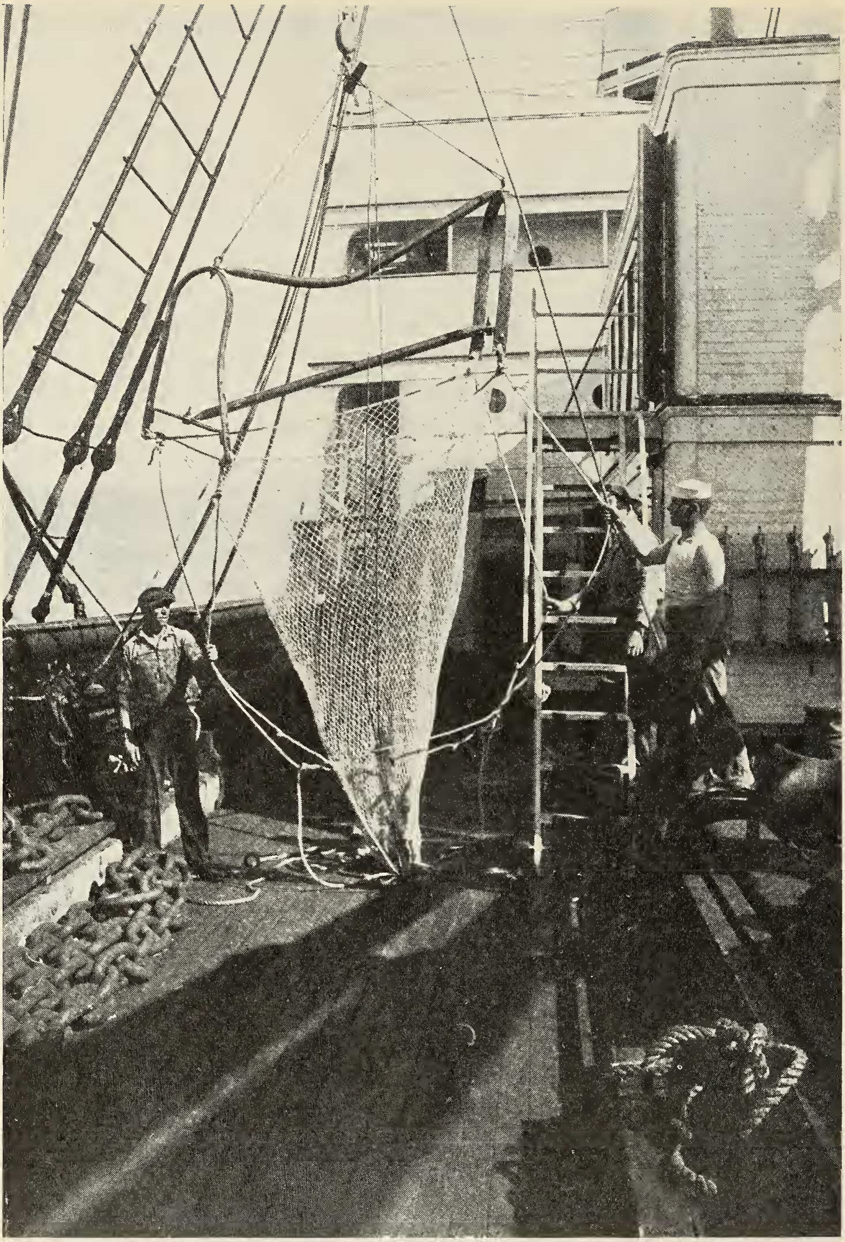

Fig. 18. A Blake beam trawl. This trawl, which is one of the ten-foot size, is shown after contact with a rock at the bottom of the Atlantic.

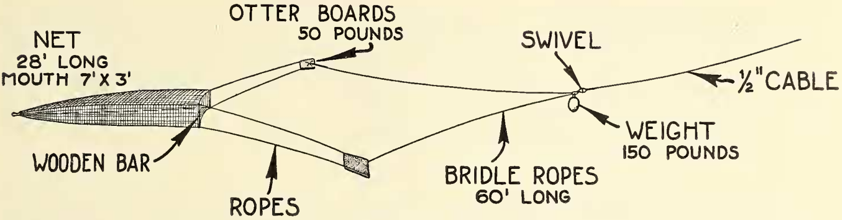

Fig. 19. Petersen trawl showing the arrangements of the otter-boards and bridle.

The trawls most commonly used varied from 10 to 50 feet across the mouth. A larger trawl, 80 feet across the mouth was lost the first time that it was sent overside. Specifications for the 50 foot net used by us are as follows:—50 feet wide from wing to wing. Mouth 40 feet wide. Net to be 45 feet long and to taper back to 10 feet, with drawstring at end. Netting 2 inch mesh, 9 thread medium. Mouth of net to be roped to ½-inch tarred manila with 4 and ½-inch cedar buoys 2 feet apart on top, three-sixteenths-inch galvanized chain on bottom.

The 10 foot trawls were for small boats. Their specifications were,—10 feet from wing to wing, 9 feet long, first 6 feet to be 1-inch mesh, 6 thread. Last 3 feet to be ½-inch mesh, 6 thread. Barked and with drawstring at end. Mouth to be roped with 9 thread tarred manila. 4½-inch cedar buoys 2 feet apart on top. 2-ounce round leads 6 inches apart on bottom.

Petersen trawls were used constantly throughout the voyage, for the most part in the middle depths. They are easily handled and are rigged and operated in much the same way as the otter trawls. They are smaller, however, and the mesh is finer. The diagram shows the most important aspects of the Petersen trawl as we used it. The specifications for these nets as supplied to the net makers are as follows:—Petersen Trawl. 7 by 3 feet at mouth, 28½ feet long, to go back straight for 20 feet and then taper for 8½ feet with drawstring at end. Netting to be ½-inch mesh, 6-thread medium barked. Mouth to be roped to 9 thread tarred manila. Four 4-inch buoys on top. Eight No. 6 seine leads on bottom.

TANGLES

During many operations tangles were attached to the end of the trawl. These were made of a bar of iron from 5 to 6 feet long to which were attached chains, at the ends of which trailed long strands of frayed rope. On very rough bottom the tangles were used alone, and they brought numerous starfish, brittle-stars and other benthonic animals to the surface.

Tow Nets

After five months of constant fishing with tow nets, we are convinced that the best type and size for general work on a ship such as the *Arcturus,* exclusive of quantitative studies, is the Michael Sars meter net. Their greatest advantage besides size, is in the coarse shrimp net collar which precedes the silk bolting cloth. This allows the water to strain through more rapidly and the net, consequently, captures a greater number of fish and other actively moving creatures that would otherwise be frightened away by the rush of water immediately in front of nets made entirely of bolting cloth. The same rush of water is felt, of course, with the Sars nets, but it is further back, and the animals apparently, are encompassed before they can escape. During the latter half of the expedition all of our tow nets with the exception of the diatom and small boat nets, were equipped with a netting collar.

On page 75 is shown a scale drawing of a Michael Sars meter net as used on board the *Arcturus.* A short explanation may help to clarify a few points in the figure. The net is cylindrical as far back at the end of the coarse OXX bolting or Dufour cloth. From here it tapers to the canvas collar that holds the plankton bucket or bottle.

The net is attached to the brass ring by means of overlapping flaps of canvas that are part of the canvas collar. The flaps are made so as to leave the bridle ropes free. They are folded over the ring and fastened by buttonholes securely sewed to the fabric. All seams are double sewed and taped,—the most suitable thread for sewing the silk portions being white cotton, size no. 60.

The larger nets were used mostly for towing beneath the surface. For surface work and for small boats we employed with a few exceptions half-meter nets.

The half-meter nets as we made them, had the bolting cloth portion similar to the specifications of the "Albatross" half-meter net. To this we added a shrimp net collar. Thus the net had a canvas collar attached to the brass ring, a half meter of shrimp net,

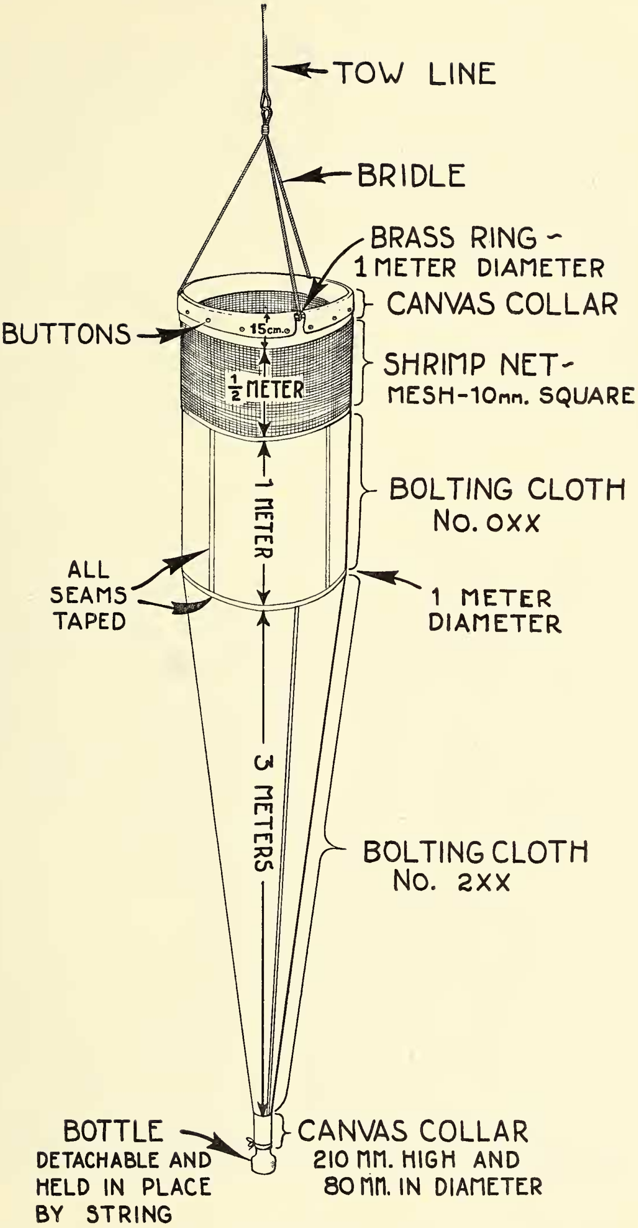

Fig. 20. A Michael Sars meter net as used on board the S. Y. *Arcturus.*

one meter of OXX bolting cloth and one and one-quarter meters of 2XX cloth. The bolting cloth, unlike that of the meter net, tapered from the half-meter diameter of the shrimp net collar, to the canvas collar at the end. This collar is 210 millimeters long and 80 millimeters in diameter. The collar at the forward end is of double thick canvas, two hundred and ten millimeters in depth.

Still smaller were the foot nets,[1] used for capturing diatoms and also for towing behind small boats. These are simply made, being 1 foot in diameter at the mouth, trailing three feet to the small end which is 2 inches in diameter. The collars are made like those of the larger nets. Those used for ordinary towing were made of 2XX bolting cloth while the diatom nets were of No. 20 standard bolting cloth.

The rings used for holding these nets were made of brass,—mostly because of its non-corrosive qualities. The rod for the meter nets was $5/8$ inch in diameter, for the half meter $1/2$ inch in diameter and for the foot rings $\frac{5}{16}$ inch.

Because of delays in manufacture, the metal plankton buckets that are fastened to the ends of the nets, did not reach the *Arcturus* before sailing, and although they chased the ship from port to port, they never did reach us. In their place we used pint mason jars which fitted perfectly into the collars. The possibility of breaking was eliminated by covering the jars with heavy burlap and inserting them into drum-shaped cigarette tins, which had contained 100 cigarettes.

When in use the neck of the bottle was inserted into the net and held in place by linen tape, which was wrapped about and tied in a bow knot. This device had advantages in being inexpensive,—mason jars and cigarette tins abound,—and in being efficient. As a net came up out of the sea, a pull on the string released the bottle, and the contents could be emptied into pans with ease. The animals were not damaged, as in some other plankton bottles, by contact with rushing water.

The canvas used on all the tow nets was 8-ounce duck. The webbing collars were in all cases made of 6-thread medium, the mesh $1/4$ inch square meshed and barked.

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[1] It is unfortunate that no single system of measurement is in use in oceanography. Meters and millimeters conflict with fathoms and feet and inches, and there is no immediate prospect of abandoning one group or the other. Hence the use of whatever measurement happens to be convenient.

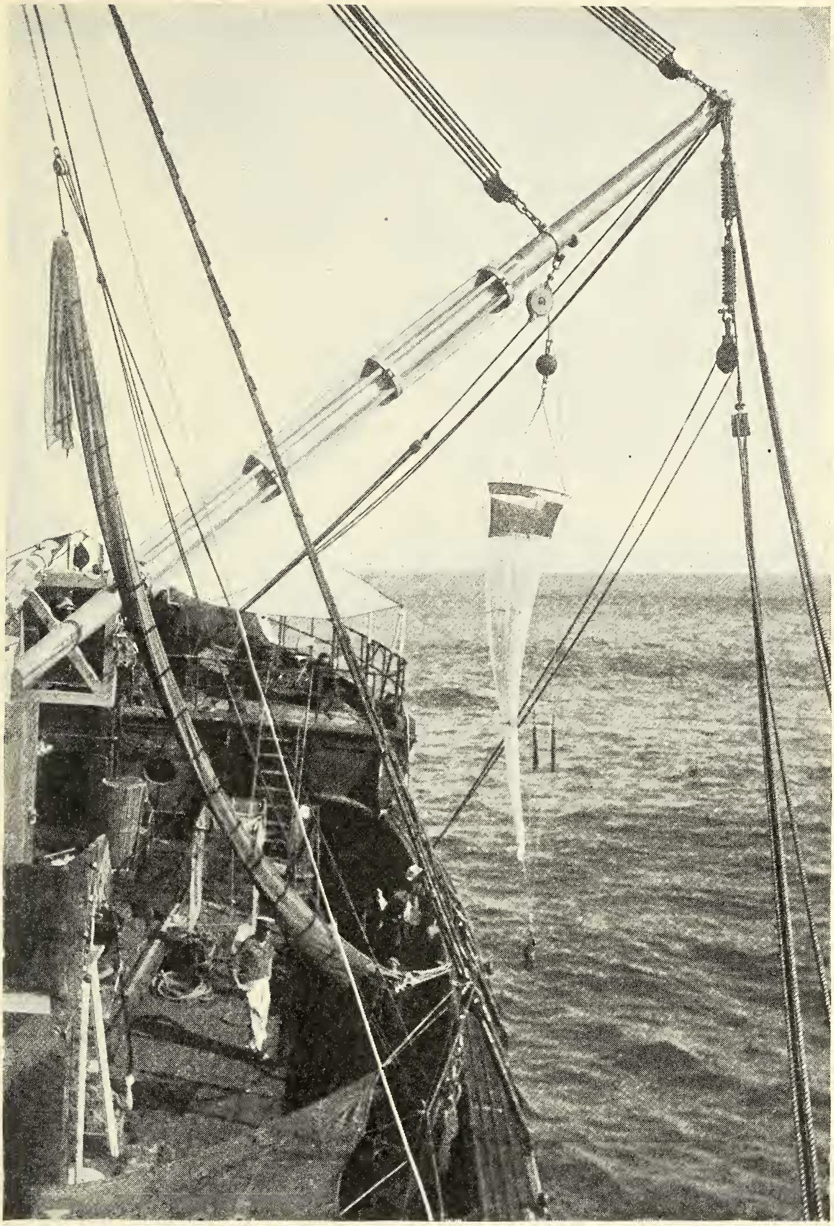

Fig. 21. Closing net of the Tanner type about to descend. The dark net hanging from the rigging to dry is a Petersen trawl.

Bridles for all these nets were made on board by the sailors. They were made of three ropes. One end of each was spliced to the brass ring while the other ends were formed into a loop at the top, into which, on a few of our nets, we placed a metal thimble. Thimbles were by no means necessary, as a rope loop will stand practically all the strain that it is likely to meet. Steel cable has been used on many ships for bridles.

VERTICAL NETS

For quantitative work with vertical and vertical closing nets we used the Tanner and the Nansen closing nets. The Tanner was used during the early part of the expedition, but was soon superseded by the Nansen.

The first few hauls in the Sargasso Sea demonstrated that in regions where the fauna was scanty the half-meter standard, vertical net did not "fish" enough. Meter nets were rigged in their place and we eventually employed them exclusively. Closing net and vertical hauls were made with both the large and the small cables.

The closing device used on the *Arcturus* was one that is employed in coastal waters by the U. S. Bureau of Fisheries. For work in deep water, however, the apparatus shown in the Pub. de Circonstance, Inter. Cons. Explor. de la Mer is undoubtedly the best device to use.

This instrument is attached to the end of the cable and the net is then fastened to it, first by means of the permanent fastening which holds the throttling rope, and second, by means of the rope which supports the net as it is pulled through the water and which is held in place by the trigger. The diagram illustrates how the net is closed by means of the messenger which is slid down the cable from the surface, tripping the trigger and releasing the supporting rope, after which the net throttles itself and is brought to the surface.

ATTACHING NETS

When dredges, otter trawls and Petersen trawls were used, the bridle was attached to the thimble at the end of the cable by means of a shackle. A heavy steel swivel was always inserted between the end of the cable and the shackle, else the twisting of the cable as it descended was very likely to foul the net.

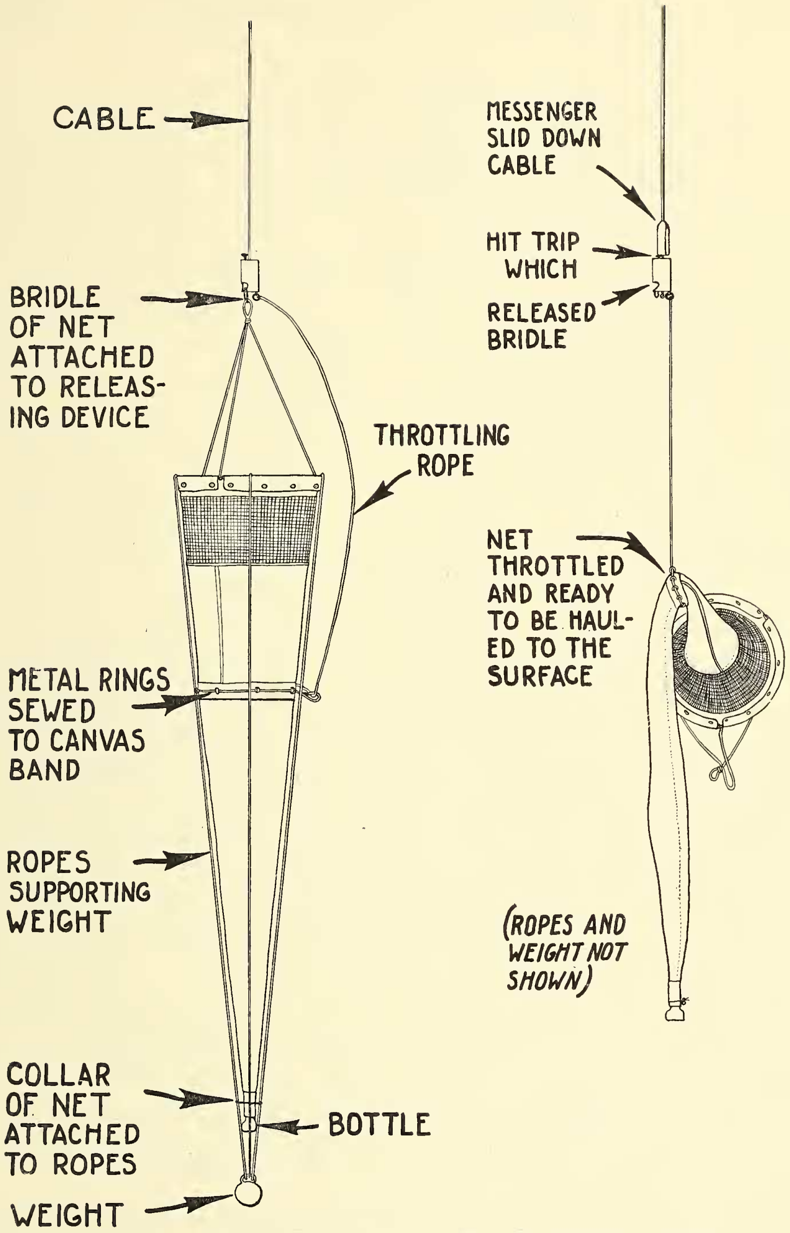

Fig. 22. Nansen closing net as used on the *Arcturus*. *Left*, net as it descended. *Right*, net after messenger slid down the wire, ready to be brought to the surface.

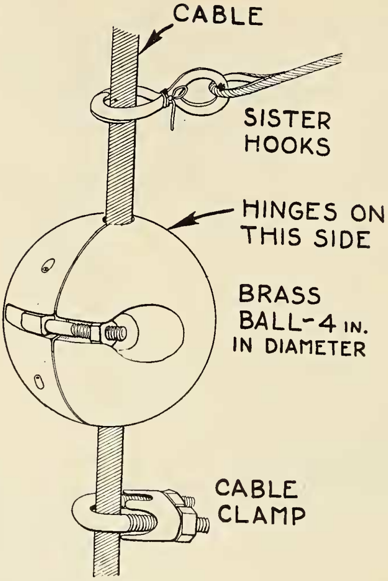

Fig. 23. Devices used to attach nets at various points along the cable.

Attaching the plankton nets to the cable at places other than the end presented a different problem. At first we used cable clamps, fastening them firmly to the wire, and then attaching the net by means of a bar fastened over the prongs of the clamp. A few experiments showed that this would not do as the nets became tangled about the cable. We then adopted the brass ball used for this purpose by the *Michael Sars.* We modified the design as shown on page 49 of "The Depths of the Ocean," by having the bolt, which tightens the ball in place, made as a part of the ball. After the ball was fastened to the wire, the net with its 6 to 15 foot leader was attached to the wire by clasping the sister-hooks about the cable above the ball. This permitted motion of the net in any direction and worked perfectly during the entire cruise.

With the exception of the Blake trawls, all of the nets were pulled downward into the ocean by means of a 150-pound ball which was fastened to the end of the cable.

It is advisable to have an abundance of cable-clamps, shackles and sister-hooks of various sizes on hand. They were constantly in use on board ship and were invaluable for attaching pieces of apparatus and for making temporary repairs.

MISCELLANEOUS FISHING GEAR

Gill nets were on board but were seldom used. About the Galapagos Islands we found that too much time was wasted in removing sharks and disentangling snarls from the nets to warrant their continued use. They were of linen, in various sizes ranging up to 300 feet by 15 feet, 6-inch mesh and made of 16–3 cord.

Seines ranging from 29 foot bait nets to 300 foot nets were part of the equipment. Nets of 70 to 80 feet long and from 8 to 10 feet deep, of 1-inch mesh were most efficient for work along beaches. Nets of this size can be easily handled by two men unless they are pulling in surf. It is most important that each seine be furnished with a bag.

Dip nets of various sizes and shapes were indispensable. Long-handled ones were especially useful, especially on a ship with high sides such as ours.

Hand harpoons of different makes were used occasionally. In addition we employed small, hand harpoon guns which discharged a harpoon and carried a small rope with the weapon.

The *Arcturus* was amply supplied with fishing tackle such as hooks, lines, sinkers, etc. Materials for set lines were also available.

Electric lights capable of being submerged were used to attract fish and other organisms within range of the dip nets.

One of our submersible lights was made of an ordinary flashlight encased in a heavy steel tube with an especially strong glass window. This was placed within traps and sent below the surface, where, it was hoped, luminescent fishes would be attracted to the traps and caught.

Many kinds of traps from eel and lobster pots to large wire contraptions of various kinds, were on board and were used whenever possible.

THERMOMETERS AND WATER-SAMPLE BOTTLES

The combined thermometer-water bottle used during the expedition was the Greene-Bigelow model, designed by Dr. H. B. Bigelow and Mr. J. V. Greene of the U. S. Bureau of Fisheries. The diagram illustrates the various parts of this machine and how they function. As can be seen, the device consists of three parts,—the reversing thermometer, the water bottle, and the releasing device at the bottom, all three of which are activated at the same time by the messenger which slides down the cable.

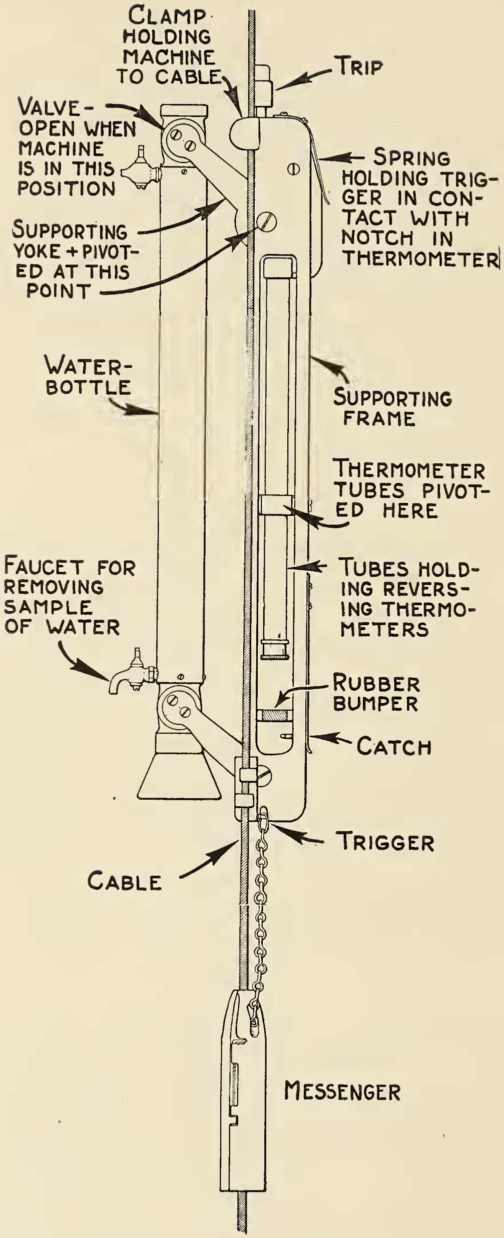

Fig. 24. Diagram of thermometer water bottle ready for descent.

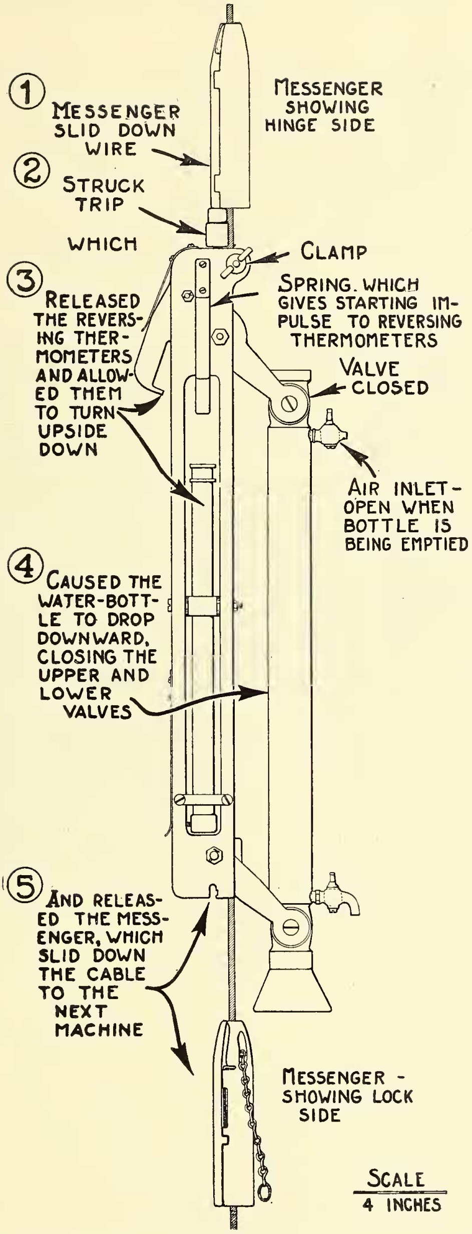

Fig. 25. Diagram of thermometer water bottle ready for ascent.

Temperatures and samples of water were taken with the ship stationary and with the thermometers fastened to the one-quarter inch cable attached to the drum of the towing engine. The cable was led over a meter wheel so placed that the winchman could easily read the dial, and thence aft and outboard to a davit placed over a platform suspended just outside the bulwarks on the port side of the ship.

When all preparations were completed, a weight of one hundred and fifty pounds was attached to the end of the cable and lowered to ten or twenty feet beneath the surface. A thermometer was then clamped to the wire and allowed to descend. Additional thermometers were fastened to the cable at predetermined distances,—all of these, with the exception of the bottom one, having a weight or messenger attached to their lower ends. The messengers are heavy, hollow, metal cylinders, made in two halves and hinged so that they could be clamped about the cable at any time or place.

After the thermometers had been sent to the various depths at which temperatures were desired, they were allowed to remain there for three or four minutes in order that the mercury might adjust itself to the temperatures at that depth. A messenger was then clamped about the cable and allowed to slide down. As it hit the tripping device at the top of the first thermometer it simultaneously accomplished three things. It disengaged a catch which allowed the water bottle to drop downward, thus closing the upper and lower valves and enclosing a sample of water. With the same motion the thermometer tubes were released and they swung about in a vertical arc so that their bulbs were uppermost. The messenger, which hung below, was released at the same time and slid down the wire until it struck the next instrument where the entire operation was repeated. And so the process went on until the last thermometer was tripped, after which they were brought to the surface, the temperatures recorded and the samples of water removed and stored in citrate of magnesia bottles.

Two thermometers made by Schmidt, and of the usual deep-sea reversing type were used at each level, so that by checking one against the other the possibility of error was extremely small. The thermometer is enclosed with an ordinary thermometer in a heavy glass tube capable of withstanding the immense pressure in the deeper layers of the ocean. These instruments are made with a constriction in the tube, just above the bulb. The column of mercury, when the thermometer is in the normal position with the bulb down, extends above this constriction, and the amount that it extends depends, of course, upon the temperature. When the thermometer is reversed the mercury breaks off at the constriction and the detached portion drops down to the opposite end from the bulb. The height of the detached stem of mercury can now be read off on the engraved scale. This reading represents the temperature at whatever depth the thermometer was reversed.

Fig. 26. Water bottle coming to the surface showing messenger resting on the wire above the machine.

The ordinary thermometer is to record the temperature at the moment the reversing thermometer is read, as corrections must be applied to the temperatures recorded, owing to the slight expansion or contraction of the glass, and the consequent slight difference between the actual temperature and that recorded.

The thermometers were examined every time they were sent down to make sure that the mercury contained no bubbles and the machines were oiled every second or third time. During the first few weeks one or two failures of a thermometer to reverse were laid to lack of lubrication. The few minutes that we spent in oiling them were well repaid. Because these devices are subjected to low temperatures, it is vital to their efficient operation that the lubricant have a low congealing point. Otherwise the machines when lowered will "freeze" and neither thermometers or water bottle will function.

After use, the reversing thermometers must be restored to their original position with bulb lowermost, and the entire device kept upright. If droplets of mercury remained detached from the main body, the thermometer was gently tapped until they connected.

Ordinary protected thermometers were employed for taking surface temperatures. These were taken by the officer on the watch, who threw a weighted bucket into the sea, and scooped up a sample of water, in which the thermometer was immersed.

Sigsbee water-bottles were included in the equipment, but were not used during the expedition.

LABORATORY EQUIPMENT

Ideas about laboratory equipment will differ on every expedition. During our trip we had the satisfaction of knowing that our supplies were ample, and that we had foreseen every need.

Our laboratory work, after the animals had arrived on board, divided itself into two parts,—first, the study of the animals in all its phases, identification, description, photographing, painting, etc. and secondly, fixing and preservation.

The study and identification necessitated a fair-sized library containing all the standard oceanographic reports, and instruments for manipulation of the organisms. Five binocular microscopes, two monocular high-power and three dissecting microscopes, besides many pocket lenses and lens holders, were in constant use. Correlated with these was a large assortment of glass slides and materials for making mounts. Drop cells are invaluable and were used for mounting the many organisms that were too thick to mount under an ordinary glass.

Other indispensable supplies were large assortments of dissecting scissors, dissecting needles, and forceps of different sizes. All our instruments were of ordinary manufacture, and nickel plated. Within a few weeks we were soon aware of the fact that salt water plays havoc with such instruments and that they ought to have been made of rustless steel.

Glass dishes of various sizes are indispensable. We found that dozens of Stender dishes 2 inches in diameter and 1 inch high, and 4 inches in diameter and 2 inches high were necessary. Larger jars 12 inches in diameter, and 3 to 4 inches high were extremely useful. Glass jars, known as household jars, 10 to 12 inches high and 8 inches in diameter were in constant demand for holding plankton.

Metal, white-enamelled pans, 16 inches long by 10 inches wide and 2 ½ high were always on deck to hold the plankton as it was removed from the nets. Higher sided pans might be advisable, except that the plankton is more easily studied and the delicate specimens can be removed with greater ease from the lower-sided containers.

Wooden and galvanized-iron wash tubs served a similar task in retaining the contents of the dredges before and during study.

Suitable paper labels were made for labelling each specimen or group of specimens. These varied in size, depending upon the containers. Most of them were small, and the details were filled in with waterproof India ink, which was thoroughly dried before immersion in the preservative. Oval zinc labels stamped with a number were attached in suitable places on the larger specimens. The zinc, however, corrodes in formalin, and is not especially suitable in that liquid.

Artists' supplies of all kinds were on board.

For killing and fixing we had ample quantities of the usual chemicals used for marine animals,—mostly those given in Lee's "Vade Mecum." Preservation of the larger forms was in the usual strength alcohol or formalin.

Proper sized containers are of great importance for preservation. If possible, each animal, especially among the crustacea, ought to be in a separate container. The possession of a single perfect specimen with appendages intact is worth more than dozens of imperfect ones which are inevitable when large numbers thrown together.

Because of this, the *Arcturus* carried vials and bottles and jars of all sorts and sizes. Homeopathic vials with the finest quality corks, (a consideration of great importance) of 1, 2, 4, 6 and 8 dram sizes were employed. Larger than these were the 4 and 6 ounce wide-mouth bottles. Especially useful for elongate fish were test tubes 6 and 8 inches long and ¾ to 1 inch in diameter and also glass jars 8 inches long and 2 inches in diameter. Glass-topped mason jars of pint and quart sizes were on board in large quantities. An assortment of these vials and jars placed in racks was always on hand in the laboratory.

Earthenware jars of 5, 10 and 20 gallon capacity were used for the larger organisms. The tops of the five-gallon jars were held in place by a spring clip, while those of the 10 and 20 gallon containers merely rested on top and were held in place by their own weight. Even in fairly heavy weather, if the crocks were not too full, but little preservative was lost. Still larger organisms were kept in 50 gallon barrels.

Most of our specimens were preserved in 75 per cent. alcohol or in 4 to 5 per cent. formalin. If necessary, we resorted to stronger or weaker grades. We always kept an alcoholometer close to the alcohol containers, especially when fresh specimens were immersed.

For the purpose of making casts and models we had an abundance of plaster of paris, beeswax and other casting materials.

AQUARIUMS

The quietness and greenness of a balanced aquarium was never attained by the fish tanks of the *Arcturus*. Owing to the rolling of the ship, the water in our aquariums was in too constant motion to allow anything to balance. Nevertheless, we were able to keep alive for months such interesting things as star-fish, serpent stars, barnacles and many different species of fish.

For observational work with salt-water fish we required an easily handled tank, not too large. Knowing that the majority of fish that we would have would seldom be over nine or ten inches long and generally much less, we had constructed a series of thirty aquariums, the largest being 23 inches long by 17 high and 17 deep, the remaining ones being slightly smaller. In addition we had forty aquariums 10 by 6 by 6 inches, a size that is practically indispensable.

All these tanks were constructed of galvanized iron, the glass being fastened in such a way as to allow the least amount of cement to come in contact with the water. All four sides and the bottom were made of glass, the bottom glass being much thicker than the sides.

The aquariums were placed on a three-tiered platform in the forward end of the starboard side of the bridge-casing. The two upper tiers had a rim 2 inches high about the outside and were lined with galvanized iron. Drain pipes led away from these troughs to the scuppers and thence overboard.

A constant stream of water was supplied to these tanks from pipes and faucets suspended above them. In order that the aquariums did not become too full, a triangular piece was cut out of the glass in the upper corner of one side.

Thus we had aquariums supplied with fresh salt water and with an outlet that allowed the surplus water to drain away. More complicated apparatus and more expensive materials might have been used, but for simplicity and efficiency this arrangement is excellent, although a few improvements are necessary.

Future changes to this group of tanks ought to consist of a new system of water supply. On the *Arcturus* the salt water came from the ship's pumps, and while this was adequate for the time being, it is insufficient for future operations. The best arrangement, as has been demonstrated in other laboratories, would be to have a pump or duplicate pumps, preferably electrically operated, made entirely of hard rubber so that no metallic substances could contaminate the water. From these pumps the water ought to be led through lead pipes and hard rubber faucets to the aquariums.

For larger fish the ship's carpenter constructed wooden tanks, approximately 7 feet long by 4 high and 2 deep. The front of these tanks was at first made of sheets of plate glass 6 feet by 3. We found, however, that glass of this size broke very easily when in a wooden tank on shipboard and we were forced to use a maximum size of 3 feet square. Apparently, it is not possible to build a wooden aquarium that will not give in some direction when the ship rolls. And as glass is not sufficiently plastic to withstand the strain, it gives way.

For the observation at close hand of the smaller fish and other animals we found that filter troughs used for microscopic purposes, answered our requirements. They vary in size and those we found most valuable were from 1 to 2 inches thick by 4 inches high and wide. They are indispensable for photography, as their plane sides give no false reflections when artificial lights are flashed upon them.

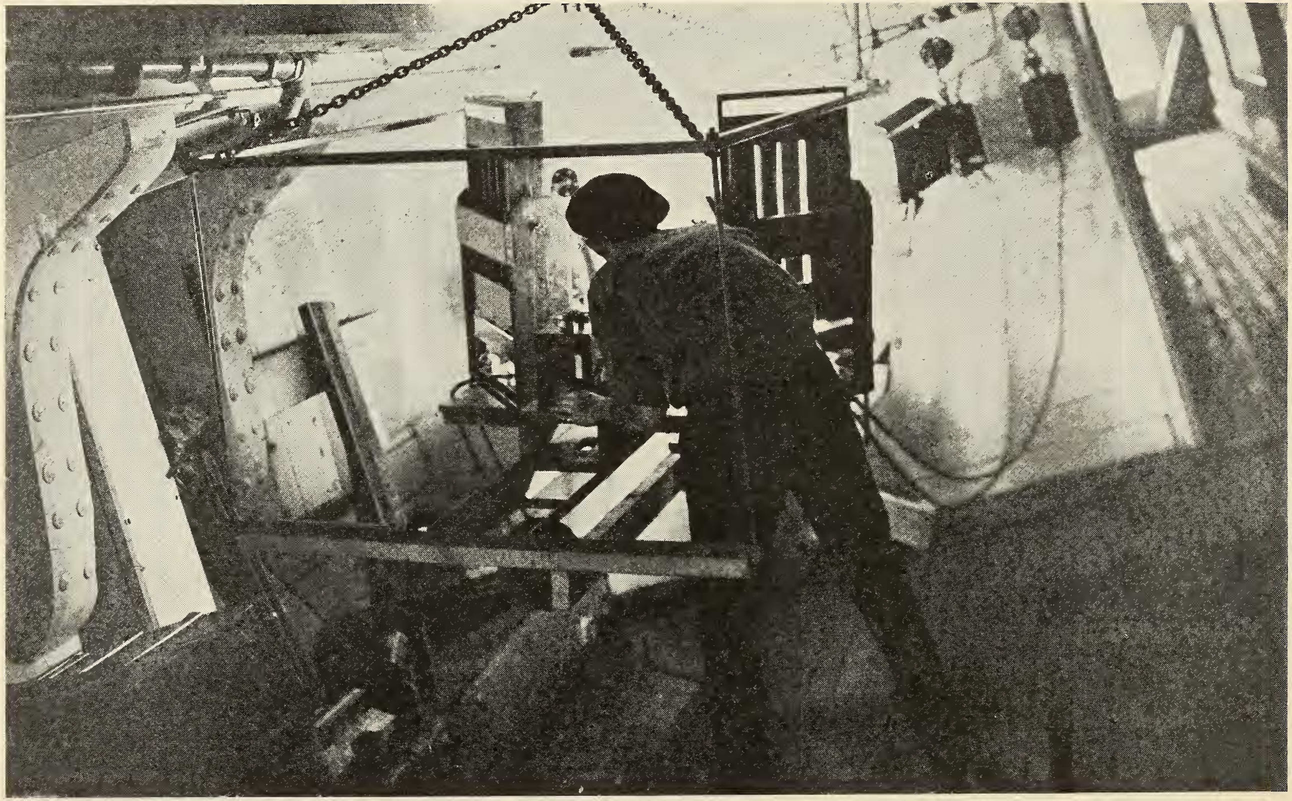

Fig. 27. Photographic laboratory showing the suspended platform.

PHOTOGRAPHIC EQUIPMENT

Photographing marine animals in aquariums filled with water is a fairly simple matter when the aquarium can be placed on a firm base. But when the stablest ground is a rolling ship, never at the same level for a second, the problem of obtaining photographs of the organisms brought up from the deep becomes somewhat complicated. To add to our difficulties, many nets containing interesting animals are brought to the surface at night. So the problem resolved itself into the production of some method whereby both the roll and pitch of the vessel could be compensated and of some way in which sufficient light could be obtained by night or day not only for still photography but also for motion pictures.

These difficulties were solved by the erection in the bridge casing, on the starboard side, of a suspended platform, fastened to the ceiling by a universal joint, which allowed it to swing forward and backward or to either side. Heavy weights were added and the result was a platform that kept its equilibrium whether the ship rolled or not. To watch an aquarium filled with water resting on this device was to doubt one's eyes, as the impression gathered was that the ship stayed motionless while the water went off at unaccountable angles.

On the platform were placed two units of Cooper-Hewitt mercury-vapour lamps, each unit containing two U-shaped tubes thirty inches long. The units were fastened in such a way that they could be moved horizontally through an arc, and if necessary, tipped forward. These precautions were necessary to avoid the possibility of reflections on the glass of the aquariums. Convenient switches made it possible to use any one or all four of the tubes or any combination. In addition a small arc lamp was used. This could be moved to various parts of the platform, so that its beam could be directed on to an object from above or below or from the side.

The objects to be photographed were placed on a movable stage, situated so as to be flooded with light from the lamps. The cameras were also on a movable stage which could be run backward or forward. The arrangement, altogether, was a very satisfactory one and many photographs were taken on it during the expedition.

Future oceanographic expeditions might improve upon this arrangement by building a room suspended in the same manner, and either heavily weighted to maintain its horizontal position or else gyroscopically controlled. I have not the faintest idea of the results of trying to work within a photographic studio that floated about more or less independent of the angles and motions of the major bulk surrounding it. But something tells me that the sea would call for its own.

The darkroom was a large room easily accessible from either the photographic room or from the main deck and the laboratories. Entrance was through a light lock—walls so arranged as to prevent the light from entering while doing away with the necessity of having a door. This arrangement was especially good when the vessel was in the tropics, as an electric fan placed in front of a ventilator caused a constant stream of fresh air to circulate. Suitable shelves, racks and cupboards were placed about the room and there was a large sink supplied with fresh water which circulated through the ice boxes before coming to the photographic room.

Of the many cameras, lenses and other photographic equipment there is very little need to write. Individual opinions vary to such an extent that other photographers would not agree with us as to what combinations are best.

Our equipment, however, contained four motion picture cameras,—one of these being of the super-speed type, capable of photographing up to sixteen times the normal speed. Graflex and suitable view cameras were also used. A wide-angle lens was found to be exceptionally useful on shipboard, as well as a 75 mm. Teleplat lens for making direct enlargements of small animals.

All developing, with the exception of the development of the motion picture film, was done on board. Tank development employing standard, prepared developers was used almost entirely.

On an oceanographic expedition where fresh water must be conserved, the problem of washing negatives becomes somewhat difficult. After a few weeks of experimenting, we decided to wash our plates and films in sea-water, after which a short thorough bath in fresh water removed all traces of the salt. This also introduced a difficulty as the water from the ocean often reached a temperature of eighty-two,—far too high for the safe development of plates. This was circumvented by bathing the plates in a solution of pure chrome alum just before they were put into the fixing solution.

WORK-SHOP EQUIPMENT

The work-shop was fitted up especially for experimental work such as making new devices for capturing marine animals and the dozens of other objects that can only be conceived and made on an oceanographic expedition. For this purpose it was equipped with a large assortment of machine, carpenter's, plumber's and other tools, in addition to a forge and a lathe.

Large assortments of wire, pipe, lumber, iron and various types of bolts, nuts and screws were aboard. The work shop was also the headquarters for sister-hooks, cable clamps and the dozens of other similar objects used daily whenever the ship happened to be trawling.

The workshop likewise contained the underwater electric lights that were used to attract animals whenever the ship was stopped.

SMALL BOATS

In addition to the life boats required by law, the *Arcturus* carried seven, small row boats. Previous experience about the Galapagos Islands during the "Williams Galapagos Expedition" had demonstrated the suitableness for work along shores and in bays and harbors of small, fairly-light, round and flat-bottomed row boats capable of holding two or three people.

Two of our boats were round bottomed skiffs, 15 feet long. The five flat-bottomed boats were 14 feet long. They were standard models,—a four-lap skiff, with longitudinally planked bottom oak frames and floor timbers, and with pine seats, two pairs of oars and oarlocks. Two of these had a glass window 14 inches square, built into the bottom, so that animals beneath the surface could be easily observed, and suitable places selected for diving. These windows were placed at the bottom of a well, so that if the glass did break, the water would be unable to enter the boat. Both the round and flat bottomed boats had square sterns, to which we attached small, portable gasoline motors.

This combination of boat and motor is ideal for work in protected situations, and it has stood up very well in moderately rough water, although it is not too comfortable under such conditions. For landing on an open beach through small surf, the motor can be tipped so that the propeller is completely out of water. The boat can run in under its own momentum or else be rowed ashore without the probability of the propeller blades hitting bottom. The weight of this combination is also a consideration. With these boats, and especially the round bottomed ones, one man can land the boat upon a beach, and by walking the boat around end for end, move it far enough in shore to be free from the possibility of destruction in the surf.

The motors used were very small, aluminum, two-horse-power machines. with self-contained dynamo, tank and cooling system. They weighed thirty-five pounds when fully equipped and would travel about twenty miles to a gallon of gasoline. The gasoline tank held five pints, sufficient to operate for twelve miles. Their usual speed was between six and eight miles an hour.

For more sea-worthy purposes two motor launches were carried, a 28 foot yacht tender with a four cylinder motor, and a 35 foot launch with a three-cylinder heavy-duty engine.

The possibility of engine trouble or other circumstances demands that these boats be adequately equipped. Ideal equipment for work about islands such as we stopped at would include oars and oarlocks, life-preserver, anchor and suitable amount of rope, extra gasoline and small funnel, wrench and screwdriver, matches in a waterproof container, and a suitable amount of food and water. Such materials take up but little room and prove their worth when called upon.

Diving Equipment

Two diving helmets were included in the equipment placed on board the ship. The usual conception of a diving suit is that of an immense bulging suit, heavily-weighted shoes, and a spherical helmet from which hoses and ropes lead to the upper world. For deep water work such an outfit is indispensable, but for shallow waters ranging down to thirty feet, such as we wished to explore, the simpler outfit employed by us and manufactured by the Miller-Dunn Co. of Miami, Florida, was ideal.

The apparatus consisted of a helmet and a pump, and a hose which connected the two. The helmet is cylindrical in form, about 22½ inches high and 10 inches in diameter, and with the lower end open and curved to fit the shoulders. The upper end is closed in, curved upward into a dome, at the top of which is a small handle by which the helmet can be carried. In front and placed at a slight

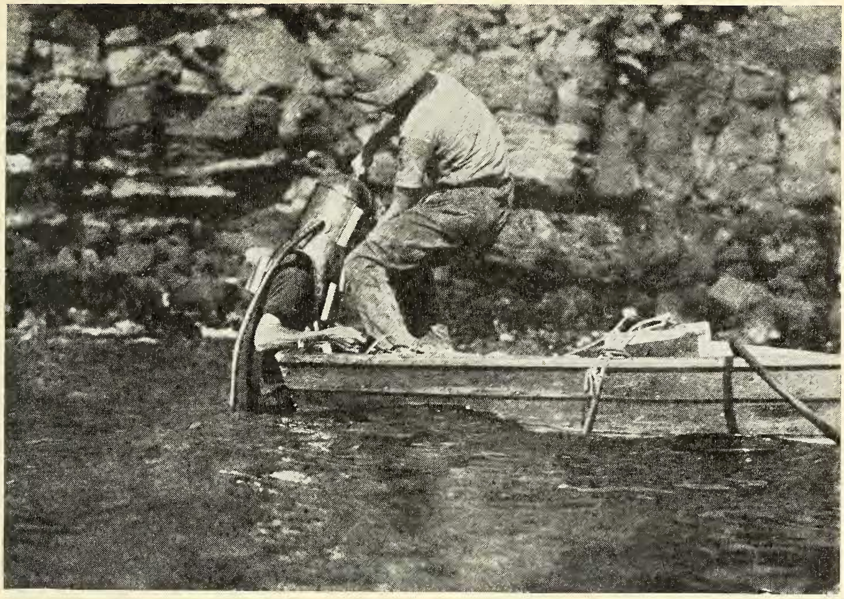

Fig. 28. Diving helmet being placed on the head of the diver.

angle are the two windows through which the diver peers. These are quite large, the height of each one being 10 inches and the width at the widest part $4\frac{1}{2}$ inches. The glass is the best plate obtainable. In case of breakage the metal frame can be removed and new glass inserted. To avoid the possibility of breakage, however, two metal bars are placed across the windows. On the right hand side just a little above one's ear is an inlet for air. On the outside this inlet is a simple pipe, bent downward and threaded to receive the end of the hose. On the inside is a small deflector, built to prevent the air from striking directly on one's ear or face.

The hose is of the common garden variety,—one of our helmets being equipped with a sixty foot and the other with a hundred foot length. It is smooth inside and out. Wire-bound hose, although less likely to kink, would be more troublesome to handle.

The pump is a very simple, double-action, automobile pump, with a long, upwardly projecting handle. It is operated by pushing the handle back and forth, the double action forcing an almost continuous stream of air down the hose to the helmet.

Four ten-pound lead weights are also a part of the outfit, and without them descent would be impossible. They are fastened by a clip to the front and back of the helmet on the portion that projects over the back and chest.

One great advantage that this helmet has over a diving suit is that in the event of an emergency the diver can free himself by throwing the helmet aside and swimming to the surface.

During practically all of the descents made the diving was done from one of the glass-bottomed flat boats, with a crew of two men in addition to the diver. After selecting a suitable situation the anchor was cast out in such a direction that the wind and current would carry the boat over the desired spot. Then a metal jacob's ladder was fastened to the boat and the lower end thrown out over the stern. The ladder that we found ideal for this work had round, wooden rungs, an inch in diameter, at the end of which were metal disks four inches in diameter. The original purpose of the disks was to keep the rungs away from the side of a ship. We found them especially useful in shortening the ladder or lengthening it, as extra portions could be added by shackling the disks together. Each rung was connected to its fellows by chains.

The pump was placed in the bow of the boat and the pumper remained seated during the task of supplying air.

In practically every descent bathing suits were worn, and a Turkish towel, whenever necessary, was wrapped about the shoulders to relieve a little of the pressure of the sixty pound helmet on protruding collar bones. Sometimes, in places where sharp coral and rocks were present, we preferred going down dressed in khaki trousers and shirt and with heavy leather shoes. When spiny sea urchins made it necessary to wear these, Mr. Beebe wore high, hob-nailed boots. Heavy shoes served the double purpose of preventing spines from entering and of keeping one's lower extremities from rising above one's head, an ever-present possibility with some individuals.

A certain amount of immunity from the coldness of the water was obtained by anointing the body with oil, and for this purpose we used raw linseed oil. Even in warm tropical waters lengthy immersion can produce a decided impression of coldness.

When going down the diver passes over the stern of the boat and stands on the rungs of the ladder, first immersing himself to the neck.

The helmet with weights in place and connected by the hose to the pump is then placed on his shoulders,—the air supply being started immediately. A single loop of the hose was placed about his arm and the diver would slowly move down the rungs of the ladder. Going down slowly is absolutely necessary, as the difference in pressure is felt immediately. Most people, especially the inexperienced, find it desirable to keep in mind as they descend, the phrase "keep swallowing." The man at the pump has meanwhile been pumping at the rate of a little less than one full stroke a second. The amount of air necessary varies with the individual, the depth and the length of time he has been under water. Enough pressure, however, must be maintained to keep the water from entering too high into the helmet. As is natural, the variation in depth is correlated with a difference in the amount of effort expended at the pump. The surplus air in the helmet escapes at the open space about the shoulders.

With this type of helmet it is not possible to lean backward or forward to any extent, as the air which normally reaches to just below the chin, soon reaches above the mouth.

Communication was by means of prearranged signals transmitted to the surface by jerking the air hose or by using a small rope for this purpose. The air-hose method is simpler and as effective.

It was the duty of the second man in the boat to take care of all the apparatus before the diver went over, to place the helmet on the diver's shoulders, to watch for possible kinks and signals in the air hose, and to lower spears, harpoons and pails to the man below, and to remove the helmet when the diver emerged. During the descent he watched through the glass bottomed well in the boat, or preferably through a water glass laid on the surface, for any dangers.

A Day's Operations on Board the Arcturus

The ultimate purpose of all the apparatus that has been described was to capture and bring to the surface the organisms found in the sea, so that they might be identified and studied and eventually brought back to civilization. Thus the frictionless running of the apparatus and of the personnel became a vital factor in the success of the expedition. If there is friction, results grow less in volume and poorer in quality. To show how our activities were correlated can best be done by describing a typical day's operations on board the ship.

Whenever possible the program for the day was worked out the night before. This schedule was typed; one copy put on a bulletin board and another given to the captain, who was thus able to communicate this intelligence to the engineering department. In this manner considerable economy was effected in the consumption of coal and water, as the fires in the boilers could be lowered hours before the time for dredging and trawling, when only a small amount of steam was necessary to keep the ship in motion.

A composite copy of one of these schedules is given below:—

Station 00

Date Locality

1. 5:15–5:45 A.M. Tow nets, surface.
    Meter #2
    Foot #20
2. 5:45 A.M. Sounding
3. Temperatures and water samples
4. 8 A.M. Trawls and tow nets.

Petersen trawl	1200 fathoms
Meter net	1200 “
“ “	1000 “
“ “	900 “
“ “	800 “
“ “	700 “
“ “	500 “
“ “	250 “
½ meter net	Surface

5. 1 P.M. Trawl, 10 foot Blake.
6. 7:45–8:45. Tow Nets, Surface
    Meter #2
    Foot #20

These schedules were followed whenever possible, but we had no compunction in altering plans. Our crew being a merchantman crew, we were limited in the workings of some of our apparatus, to eight hours a day. This limited also the length of time that our nets and dredges could be towed. A string of nets such as shown in the schedule takes a long time to lower and raise, and in order to bring them in before the men went off duty sometimes meant taking a half hour from the time that they could be towed. The general run of hauls, however, were with a smaller number of nets than is shown in the schedule, which gave a considerably greater towing interval.

Before beginning with the daily happenings it may be well to mention the few tasks that were constantly attended to by the officer on watch. While at sea, in addition to the regular information that is recorded, such as temperature, barometric pressure and the conditions of wind and sea, this officer took observations every two hours of the temperature of the water at the surface. At the same time he threw a drift bottle into the ocean,—an ordinary, glass, soda-water bottle, tightly corked, inside of which was a printed slip containing a number. This number coincided with the latitude and longitude of the place where the bottle went overboard.

The printed slip contained a request that the slip be returned to the Hydrographic office of the United States Navy or to the Zoological Society with the finder's name and address and information as to where it was found. Exceedingly interesting observations have been made as the result of bottles of this type. Some have travelled thousands of miles from where they started.

Before daybreak, in the tropics usually at 5.15 A.M., the ship was slowed to two knots and the first plankton nets, usually a meter or half meter net of coarser bolting cloth, and a foot net of No. 20 cloth were thrown overboard and towed.

Plankton organisms are usually near and at the surface during the night, and they start to migrate downward soon after the appearance of dawn. Thus in order that representative samples be taken it was necessary that these nets be towed before day-light in order that an adequate sample would be obtained. The length of time during which the net was left in the water varied with the locality and with conditions of weather. In the Pacific, from Panama to the Galapagos Islands, 15 to 20 minutes would not only fill the bottle at the end of the net, but the plankton would often extend in a solid mass for six or eight inches above the bottle. In contrast to this abundance were our hauls in the Sargasso Sea, where an hour's haul would result in a thin layer of animal life at the bottom of the jar and a few sprigs of sargassum weed.

During the first few weeks of the expedition the tow nets were towed from the poop, but subsequent work demonstrated that the boom-walk was a more convenient place. The length of rope needed varied with the net and with the height of the ship out of water. If the net came out of water too much, as the ship dipped, the tow line was lengthened or a 10 to 20 pound weight added until the net remained just beneath the surface. Rope less than ½-inch in diameter was not used, as a sufficiently strong grip can not be had with a smaller rope.

We found that a man could not pull in a meter net while the ship went ahead, although he could pull in a half-meter net. So we attached a second line to the bridle and led it back to a place abeam of where the net towed. From this situation the net could be lifted out of water and hauled aboard with the greatest ease. During the early morning hauls, however, this was not necessary, as the ship was stopped at the end of the tow in order that the sounding could be made.

Soundings were made with the ship stopped and held as stationary as possible with the bow toward the wind and sea. As the sounding line must be vertical it was often necessary, especially in heavy winds, to start the engines and maneouver the ship during the sounding until the line was straight.

The proceeding in sounding was in most cases as follows:—After the sound wire was led through the meter wheel and pulleys and the tube attached to the end, the sounding weight was attached to the tube and allowed to swing clear of the boom-walk. Then, when the officer on the bridge signalled that the ship had stopped and that he would keep her steady, the weight was allowed to run out. When the weight touched bottom, the time and depth in meters was recorded and the wire reeled up. The time for a sounding in 2803 fathoms (5126 meters) has already been given. At Station 78 in 1323 fathoms, or a little over a land mile and a half, the complete sounding was made in 20 minutes.

As the reeling-in progressed the surplus water was removed by passing the wire through two or three thicknesses of heavy burlap. A film of oil was flowed over the wire on the drum. Automatic oiling devices were made, but they were not especially successful. Eventually the oiling was done with a small brush dipped in oil which was applied to the wire after each layer was wound.

When the "stray line" reached the surface the reeling in was slowed down until the sounding tube was in the hands of the operator. The tube was then unfastened and taken to the laboratory where the bottom sample was removed. This was done by pressing the plunger at the bottom which opened the valve and let the sample pour out. Especial care was taken to see that all the sample was removed. Sticky oozes and especially some of the clays often become firmly attached to the inside of the tube and especially to the valve seats. The tube was afterward cleaned and stored for the next descent.

The surplus water in the bottom samples was removed and the samples stored in bottles. As most of our samples, after determinations had been made as to bottom-types, were to be examined for the presence of nematodes, they were treated with corrosive sublimate before they were preserved.

The usual sounding crew consisted of three men,—the operator of the machine, a man who recorded the depth and time, and the man on the boom-walk who attached the weight, removed the surplus water from the line as it came up, and disengaged the tube with its attendant sample.

With the depth known, such operations as taking temperatures, and trawling and dredging could begin. Whenever possible temperatures were taken early in the morning before the nets were submerged. If the sounding had shown it to be necessary the depths at which the nets were to be sent was modified.

For temperatures four persons were required,—a winchman, one to record the temperatures and label the samples, and two men on the platform, who attached the machines, read the thermometers and bottled the water samples. During high winds an extra man was delegated to pull the cable close in to the ship by means of a block and tackle that was attached to the wire whenever a thermometer-water-bottle had to be attached. This was necessary at times because the ship, when the thermometers were in use, could not always be held head to the wind and sea. If the ship was held to the weather there was always a likelihood that she would slew around and over the cable, and if this happened there was a possibility of scraping a thermometer off the cable as it came alongside the hull. To obviate this we tried to have the wind on the port bow or abeam. Thus the ship made leeway and as the wire described a slight curve away from the side we found it necessary to have the extra man. The procedure and operation of the thermometers has been given in the section on Thermometers.

When working at night we found that a small electric flashlight with dimly-shining bulb was most efficient for reading the thermometers.

Breakfast was at seven in the morning. Before 8, whenever possible, the meter nets were examined for holes in the fabric or other deficiencies and the plankton bottles were tied into the ends.

At 8:00 the winchmen and sailors came on duty and prepared the machinery for trawling. A Petersen trawl was attached to the end of the cable. The bridle was then hauled up until the boards were up as close to the pulley at the end of the boom as they could go. The ship meanwhile, was under slow headway, moving at a maximum speed of 2 knots, and with only the port propeller in action. The trawl was put over-side and trailed in the water. It was allowed to pay out until the end of the cable passed the deck, when it was stopped and the 150 pound weight attached to the end of the cable. Then, if the otter boards were pulling in the right way, more cable was let out and the net, boards and weight slowly left the surface. After 20 meters of wire was out the drum was stopped and the cable drawn in toward the side of the ship, in order that a meter net could be attached. All of these distances between nets were measured by the meter-wheels, and one of the staff was always detailed to see that the correct measurements were made.

The cable was often a considerable distance from the ship and to bring it alongside, we either threw the stern of the ship over, so that the wire came alongside of the hull, or else, under certain conditions, pulled the cable in by means of a hook and rope attached to a donkey engine. The wire when nets were being towed usually came alongside the ship just aft of the foremast stays.

During the first part of the expedition, as I have mentioned, we fastened the nets to the cable by means of cable clamps, and later we used the brass balls. Subsequently, we found that the hinges on these spheres had been constructed too weakly, and in order to make certain that they did not slip down the wire because of this, we placed a cable clamp beneath them. The net was then fastened to the cable by means of sister-hooks. When this was done the wire travelled out again, slowly until it was evident that the net would be clear, and then more rapidly. The process was repeated until all the nets were on the line and they were then towed the desired length of time.

At Station 113, 100 miles outside of New York, six meter nets were sent down at 100 fathom intervals from 500 to 1000 fathoms, and a Petersen trawl just below the lowermost net. The entire operation of fastening the nets and sending the cable down occupied 1 hour and 9 minutes. Attaching the nets took 15 minutes and the remaining 54 minutes were occupied in letting the cable out. Bringing them in was a somewhat lengthier process, the whole proceeding taking one hour and fifty-five minutes.

In the afternoon of the same day a similar series of nets were sent down, also at 100 fathom intervals, from 700 to 1200 fathoms. These were sent to their respective depths in 59 minutes, 16½ minutes of which were with the cable stopped while the nets were being attached. As with the preceding group, coming to the surface was slower, taking 2 hours, 20 minutes of which were used in removing the nets.

These two hauls were made at slightly greater speed than usual. The rapidity of such operations depends greatly upon the training of the crew and the facility with which the nets can be handled.

In all cases, when nets or Petersen trawls were towed, the amount of cable out was always 50 per cent. greater than the actual depth. Thus to send a net to 100 fathoms required 150 fathoms of line, to take care of the fact that the line went down at a 45 degree angle. When towing on the bottom the length of line was often considerably greater than this.

The length of time that such nets were hauled varied in the same way as was mentioned for the surface nets. In densely inhabited waters such as we found in the Pacific a half hour or less would result in a full bottle. At Station 113 the hauls were all short, one being 30 minutes and the other forty-four minutes. While coming up all of these nets strained through a zone of Salpa, and each one came to the surface with two to three pailfuls of those interesting, crystal-like animals.

One or two experimental hauls ought to be made in each region to determine the most suitable length of time for towing. In certain regions of the oceans, hours of horizontal towing are necessary to obtain a representative view of the fauna.

Bringing the nets in was similar to that of sending them out, with the exception that we took turns in beating the cable, while two men were detailed to see that the cable rolled up on the drum in the right way. This was usually done so that the last net arrived on board by 12:00 o'clock, when the crew went to lunch. As the nets were brought alongside the ship they were removed from the line, the bottles taken out, their contents emptied into a pan, and the organisms immediately sent to the laboratory for study. The members of the staff also had lunch at 12:00 after which the afternoon's nets were prepared for action. At 1:00 o'clock the men again came on duty and lowered the dredges or trawls or whatever happened to be on the program.

When otter trawls were used the procedure of putting them over was similar to when the Petersen trawls went out. But owing to the greater length of the bridle, we found it necessary to carry the net back to the poop and put it into the water from there. As the net went into the water and the boards opened out, the stern was swung slightly to port until nets and boards were completely free from any possibility of fouling. The otter trawls were used occasionally for intermediate towing, but they were practically always sent to the bottom. At Station 74 we lowered a trawl to 650 fathoms for one of the best hauls made during the expedition. For this purpose we used a 40-foot trawl with 150-foot bridles, 50-pound otter-boards, a 150-pound ball at the end of the cable and a 50-pound ball at the end of the net. This net took 49 minutes to reach the bottom and 50 minutes to come up, after having towed on the bottom for 1 hour and a half.

When we sent down the Blake trawls the weight at the end of the cable was omitted. They were slowly lowered, while the ship crept ahead. When on the bottom after a sufficient amount of cable was allowed out, they were towed for whatever length of time was deemed sufficient. A Blake trawl lowered in 844 fathoms arrived at the bottom in 28 minutes, was slowly towed for 2 hours and came to the surface in 38 minutes. The time for descent and ascent, especially the latter, varies considerably, depending upon the conditions of sea and what the dredge has encountered on the bottom.

If the dredge arrived at the surface with a large amount of mud in the bag, it was emptied on deck. The mud was then placed in sieves and, by playing a stream of water over it, the animals were soon revealed.

The operation of dredges and trawls and tangles that dredge on the bottom differed from the working of the other nets in that the towing apparatus was connected with the cable. But as this machine was automatic it made no difference in the number of men needed. The chief officer, however, usually watched the dynamometer at the base of the towing engine, and the amount of tension was recorded every time there was an appreciable change.

The men necessary for a dredging or meter net operation consisted of a winchman, two men to lead the cable on the drum and to oil it, two men to attach the nets, the chief officer who controlled the operations, and a member of the staff who watched the meter wheel, calculated the depths and generally supervised the work.

When the vertical nets were used, the ship was stationary. The cable was rigged through the sheave on the davit over the platform on the port side, or through a pulley on the dredging boom, as shown in the illustration on page 77. This allowed the nets to come alongside in a place where they could be easily handled.

These nets, rigged in the same way as the vertical closing net, except that the closing arrangement was omitted, were put over the side, sent to a certain depth and then slowly hauled to the surface. They were sent down a number of times, the depth at each immersion being increased. Thus we made a series of hauls, say from 500 meters to the top, then from 600 up, and then from 700, 800 and 900, and so on. This gave us a fair idea of what animals were in the different zones.

The use of vertical closing nets was a more definite method of accomplishing the same object. These nets, rigged as on pages 77 and 79 were sent to the various depths, raised a certain distance, closed by means of a messenger sent from above, and then brought to the surface. Thus the animals living in the zone between 800 and 1000 meters were caught by sending the net down to 1000 meters, hauled to 800 meters, closed and brought up.

Where the fauna was scanty the closing net was towed within the zone that was to be investigated. Let us use the 800–1000 meter zone again as an illustration: The net was sent to 1000 meters. Then the ship started forward slowly, great care being taken to watch the angle of the cable. If the angle became too great and the calculations showed that it was approaching the 800-meter line the ship was slowed down until the angle lessened. Then the net pulled in to the 800-meter line closed with its haul and raised to the surface.

The contents of the vertical nets were carefully saved as their importance lies in saving every organism taken in the net, so that they might be counted and an estimate made of the richness of life in whatever zone was examined.

At 5:00 P.M. the trawling crew went off duty, and between 5:30 and 6:00 the staff had dinner.

At night a series of surface tow nets were thrown over, often at half-hour intervals. Twice during the expedition, surface nets were thrown over for 30 minutes of each hour for 24 consecutive hours. This gave an interesting cross-section of when and in what order the plankton animals rose to the surface.

Complete records of all proceedings and captures were taken. Thus the contents of each net and the conditions surrounding each capture were carefully recorded, in addition to the physical details of each station and the many other observations that were made more or less automatically.

The details of a typical day's activities must of necessity be considerably varied, and this account represents but a fragmentary portion of the ship's operations. The contact with land has been omitted entirely. Yet it is hoped that, meager as it is, this account will give a faint view of what our equipment was like and what we did with it.